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THE

PRINCIPLES AND PRACTICE

OF

HYDRAULIC ENGINEERING;

APPLIED TO THE

CONVEYANCE OF WATER, THOROUGH-DRAINAGE

AND MILL POWER;

ALSO,

TABLES OF EARTHWORK,

FOR FINDING THE

CUBIC QUANTITIES OF EXCAVATIONS AND EMBANKMENTS,

IN RAILWAYS, ROADS, RIVERS, DRAINS, &c.

FOR THE USE OF

CIVIL ENGINEERS, LAND SURVEYORS, DRAINAGE INSPECTORS,
LAND AND MILL PROPRIETORS, OVERSEERS, ETC.

BIBLIOTHECA BODLEIANA

BY

JOHN DWYER, C.E.

DUBLIN
JAMES M^c^GLASHAN, 21 D'OLIER-STREET.
W. S. ORR AND CO., 147, STRAND, LONDON.
FRASER AND CO., EDINBURGH.
MDCCCXLVII.

TO

COLONEL HARRY D. JONES, R.E., M.R.I.A.

MEMBER OF THE INSTITUTE OF CIVIL ENGINEERS, LONDON;
CHAIRMAN OF THE BOARD OF PUBLIC WORKS,
AND PRESIDENT OF THE INSTITUTE OF CIVIL ENGINEERS
IN IRELAND.

SIR,

THE kind disposition, and generous zeal, by which you are prompted to patronise whatever tends to the advancement of Science and Literature, must command the admiration of all.

Notwithstanding your close and assiduous attention to the discharge of the varied and onerous duties devolving on you as Chief Commissioner of Her Majesty's Board of Public Works in Ireland, you are enabled to devote sufficient time in presiding over the useful and scientific disquisitions of the Institute of Civil Engineers, watching its progress with anxious solicitude, and by your presence giving encouragment to him who has just entered on the arduous duties of his profession, as well as sanctioning, by your meed of approbation, the enlightened labours of those of more matured judgment.

To whom then could I more appropriately inscribe the following pages, which I hope will be found of practical utility, than to one who is as intimately conversant with the varied departments of his profession, as he is indefatigable in his exertions for the promotion of General Science?

I have the honor to be, Sir,

With the greatest respect,

Your most obedient, humble servant,

JOHN DWYER.

PREFACE.

ALL who contemplate the Works of Nature, must admire the economy and nice adjustment of the Mechanical Motions and Phenomena of Running Waters; and few of her operations afford more frequent opportunities of observing the simple means by which she invariably attains the most important results. But, notwithstanding this apparent simplicity of her operations, it requires much time and labour, as well as great experience, attention, and perseverance, to become acquainted with the multiplicity of circumstances which contribute, and are necessarily combined, to effect the results of the simplest cases of Hydraulic Motion. "To wish," says a judicious writer, "to know the nature of the Elements, is vain, our gross organs are insufficient for the study; to suppose what we do not know, and to fancy shapes and sizes at will, is only to raise phantoms which may produce a system, but will never prove a foundation for any science; but to investigate Nature herself, to study the laws which she so faithfully observes, to catch her, as we say, in the fact, and thus wrest from her the secret—this is the only way to become her Master, and the only procedure consistent with good sense and judgment."

Sir Isaac Newton, with his usual penetration, distinctly observed this *modus operandi* of Nature, and applied himself to the investigation of the manner in which the acknowledged powers of natural bodies, acting according to the received laws of Mechanics and Hydrostatics, influenced the results, with a view of discovering its cause. The Abbe Bossut, at Paris, was also engaged by his Sovereign to make such experiments on the motion of water as his judgment would lead him to conceive necessary. With that view, a tower of superior strength was built, to serve him as a *reservoir*, from which water was to issue through orifices of various figures and dimensions, and subject to a pressure of from 5 to 22 feet of water. A Table of the comparative results of some of these experiments is given in page 79. Then followed the famous Chevalier De Buât, who resumed this subject where Bossut left off, and prosecuted the study with such assiduity, perseverance, and success, as will transmit his name, in connexion therewith, to the latest posterity—*Vide* pp. 11 and 78 ; and it is from the principles established by him, (being the results of the vast number of his experiments,) that the Hydraulic portion of this work has been chiefly calculated. Neither should the valuable labours of Etelwein, Venturi, the Marquis Poleni, Brindley, Euler, Bernouelli, Young, Tredgold, and Smeaton be forgotten ; nor, though last, not least, those of Sir Robert Kane, whose superior work on the "Turbine Wheel," just published, displays that penetration, judgment, and ability which characterize his other invaluable works. To it and his "Industrial Resources" I would recommend the attention of every philanthropist and patriot—*Vide* p. 98.

In the course of this work I have frequently consulted the excellent articles on Water-works, Hydraulics, Rivers, &c., in the "Encyclopædia Britannica;" and when the opinions of others are quoted, the author is given. The Rules, which will be found numerous and explanatory, as well as the eighteen principal Tables, are exclusively my calculation, and I alone am responsible for any fault or error they may contain. They are all original and new, with the exception of Tables 17 and 18, of Excavations and Embankments, which, although mine, were published ten years ago in another's name; I have remodelled, corrected, and improved them, and now take leave to resume them in this work. But in doing so, am most anxious that it should not imply any invidious insinuation against that person, as my object is only to vindicate myself against the imputation of having appropriated that which apparently belonged to another. The other Tables were principally drawn up for office use, and are now, at the request of several eminent Engineers, published to meet their wishes and convenience, as well as for those engaged in River and Thorough-drainage, the Conveyance of Water, Mill Power, &c.

The want of a work in the Hydraulic department, sufficiently practical, has long been felt, there being nothing of the kind extant, that I am aware of. We frequently hear parties proposing "to widen, deepen, and straighten, so as to afford the waters a free passage," but they seldom state precisely to what extent these operations should be carried. The difficulty and intricacy of the calculations necessary to the investigation, rendered it very troublesome, which, it is hoped, this work will obviate, for no Drainage measures can be carried out efficiently unless based on the fundamental principles of Hydraulics.

The extensive experience and frequent opportunities I have of testing the utility and accuracy of these Tables (being engaged in the Drainage Department of the Board of Public Works), enable me to speak with confidence of the certainty of their results. By them, the Engineer, &c., will find his time economized, and materially abridged, and the intricate combination of varied data, involving abstruse and laborious investigations, presented to his view in a Tabular form, suited to his immediate necessities, as well as to the comprehension of the humblest capacity.

Should any one employed professionally or otherwise profit by this work, or should it be the means of inducing some abler hands to take up this now all-important subject, with a view to the advancement of science and the prosperity of our common country, I shall feel conscious of having contributed my mite to so laudable an undertaking.

J. D

DUBLIN,
30, AUNGIER-STREET.

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ERRATA.

For " long," in page 19, line 7, *read* " being."
For " Captain Larcom," p. 21, line 8, *read* " Captain Larcom, R.E."
For " Table 6th," p. 31, line 10, *read* " Table 14."
For " conducts," p. 32, line 28, *read* " conduits."
For " cubic feet," p. 34, line 21, *omit* " cubic."
For "$\overline{3.6}^2$", p. 38, line 22, *read* "$\overline{3.5}^2$," and " 12.25" for "12.96."
For " $\sqrt{\overline{rh^2+hB}}|^3$," p. 41, line 3, *read* "$\overline{rh^2+hB}|^3$."
For "$2\,(h^2+hB)^3\,55^2$, p. 41, line 4, *read* "$2\,(rh^2+hB)355^2$."
For " 1 ft. 4 in.," p. 60, fall 2 ft., *read* " 1 ft. 3 in."
For " vicidity," p. 80, lines 23 and 29, *read* " viscidity."
For " feet," p. 84, line 15, *read* " foot."
For " ration," p. 102, line 14, *read* " ratio."
For " velocity," p. 104, line 4, *read* " square of the velocity."
For " 60," p. 104, line 18, *read* " 60^2."
For "2475.72," p. 104, l. 31, *read* "$2475.72 \div 60 = 41.26$ the resistance."
For " Section 17," p. 119, *read* " Section 18."
For " Ah," p. 131, line 22, *read* " Ak."
For " 25," p. 134, last line *read* " 15," and "1275" for " 1257."

HYDRAULIC TABLES.

SECTION I.

OF RIVERS AND THEIR USES.

A **River** is a current of fresh water flowing from its source, through a bed or channel, to the sea.

Rivers form one of the principal features of the surface of the earth, serving as conduits for the discharge of the surplus waters of rain and springs; they also serve as barriers, boundaries, and highways, and fertilize the soil by depositing in the valleys the rich mould, which, in their rapid descent, they carry down from the mountains during times of flood.

Pliny observes, that, in general, their origin, progress, and many other interesting features of their character bear some resemblance to the life of man. "The River springs from the earth, but its origin is in Heaven; its beginnings are insignificant, and its infancy frivolous; it plays among the flowers of a meadow, it waters a garden or turns a little mill: gathering strength in its youth, it becomes wild and impetuous of restraints which it still meets with; in the hollows, among the mountains, it is restless and fretful, quick in its turnings, and unsteady in its course: now it is a roaring cataract, tearing up and overturning whatever opposes its progress, it shoots headlong down a rock—then it becomes a sullen and gloomy pool, buried in the bottom of a glen; recovering breath by repose, it again dashes along, 'till, tired of the uproar, it quits all that it has swept along, and leaves the openings of the valley strewed with the rejected waste. Now, quitting its retirement, it comes abroad into the world, journeying with more prudence and discretion through cultivated fields, yielding to circumstances and winding round what would trouble it to overwhelm or remove, it passes the populous cities and all the busy haunts of man, tendering its services on every side, and becomes the support and ornament of the country; now, increased by numerous tributaries and alliances, advanced in its course of existence, it becomes grave and stately in its motions, loves peace and quiet, and in majestic silence rolls on its mighty waters, till it is laid to rest in the vast abyss of the deep."

Such is the beautiful description given of a mighty river from its source to its final entrance into the great parent of all—THE OCEAN.

The importance of this subject of Rivers needs no commentary, as every nation, country, and city is interested therein; for our wants, our comforts, and our pleasures require an intimate acquaintance with their nature and principles. We must conduct their waters to our dwellings, secure ourselves against their ravages, render them subservient to our wants in propelling machinery, thereby making a few able to perform the work of thousands—they fertilize our fields, decorate our mansions, clean and embellish our cities, preserve and extend our demesnes, transport our superfluities, and supply us, in return, with the superabundance of other climes.

To do these things, we must confine and govern the mighty, preserve the smaller, and draw from them supplies to irrigate our fields, drive our machines, and supply our canals for the purposes of navigation.

We must understand and discover their secret, slow, and unceasing action, that our bridges, wharfs, docks, and quays, may not fall a prey to their resistless force and become a heap of ruin. Ignorant how to proceed in those intricate and frequently recurring cases, we often see projects of high expectation and heavy expense fail of their objects, leaving the state burdened with works not only useless, but frequently hurtful and injurious to society.

The Abbé Bossût, and after him the Chevalier De Bûat, prosecuted the study of the motion of Rivers and Fluids with great perseverance and success. The latter, after considerable study and deliberation, saw the folly of attempting to deduce an accurate theory from any principles that were yet known, and the necessity of adhering strictly to such as could be deduced from experiments only, independent of any more general principles; he, after innumerable experiments made under various circumstances, saw that such a theory must be a just one, and, having maturely considered the subject, he happily conceived such a rational view of it, as rendered unnecessary the minute consideration of the small internal motions of its particles, and enabled him to proceed on the following general proposition: "*That when water flows uniformly in any channel or bed, the accelerating force which obliges it to move is equal to the sum of all the resistances which it meets with, whether arising from its own viscidity or the friction of its bed.*" He, with great penetration and singular address, reduced every section of a River to a rectangle of the same area, having a base equal to the perimeter of the section in contact, which he called the "border," or radius of the Section, and the height that this rectangle would stand at, he called the "*Hydraulic Mean Depth*" of the Section, and as the resistance increases with the "border," it is evident (*Cœteris Paribus*) that the greater the Border the less the Mean Hydraulic Depth, and thus, by duly appreciating the part each co-operating circumstance had in producing the complicated phenomenon of its motion, he ultimately succeeded in establishing a Formula, which has stood the test of the most rigid scrutiny, and conferred lasting services on practical science, viz. :—

$$\frac{307\sqrt{d-.1}}{\sqrt{s}-\mathrm{L}\sqrt{s+1{\cdot}6}}-{\cdot}3\sqrt{d-{\cdot}1}=\text{Velocity per second.}$$

This Formula is founded chiefly on observations made on small Canals, Mill-courses, and Conduits for working machinery, in which application it is most accurate—it is from this formula that Tables 6 and 7 have been deduced.

The principal circumstances which tend to affect the motion of a River are, the extent of its tranverse section, usually called its *Sectional area*, its perimeter or "border," and the inclination of its bed or surface, each of which contribute, in a greater or less degree, to the production of the general effect.

The motion of a River arises chiefly from the action of gravity and the mobility of its parts, which make them assume a level, or determine them in the direction of least resistance; thus, when the surface of water is level, all is quiescent, otherwise every particle would tend towards the lower side, and this tendency or inclination of the particles is not confined to those on the mere surface, but pervades the entire mass, which phenomenon has considerably embarrassed and perplexed the sagacity of many of the most eminent men, in their attempts to reduce it within the known laws of reason and science. But as my object here is not theoretic speculations, but practical results, I shall direct the attention of the reader to the mode of calculating these HYDRAULIC TABLES, that their accuracy may be tested and the principles on which their construction is founded, examined.

I do not pretend to have made any new discoveries in the principles of the science, but I may be permitted to say, that by a judicious use of these Tables, ENGINEERS, &c., particularly those employed on the general drainage now being carried on in these countries, will feel greatly relieved from the tedious intricacy of those calculations in Hydraulics, which are indispensably connected with the due discharge of their professional avocations, when engaged in the drainage of land, the conveyance of water, construction of canals, or the erection of mills.

The authorities consulted, besides those already mentioned, are Venturi, Young, Bland, Tredgold, Sir Isaac Newton, Dr. Lardner, &c.

It would be ungrateful of me, did I not here acknowledge the great and important services derived from the suggestions, founded on extensive experience and professional acumen, of JOHN MAC MAHON, Esq., Engineer to the BOARD of PUBLIC WORKS in IRELAND; for which, and his many other kind offices, I beg to tender him my most sincere thanks and grateful acknowledgments.

SECTION II.

OF THE QUANTITY OF WATER WHICH ANNUALLY FALLS IN THESE COUNTRIES.

In Ireland, the moisture of the climate is its greatest defect; but this varies remarkably in degree, the atmosphere on the western side being much more humid than in the east. The greatest quantity of rain which has been known to fall in the year is 42 inches, which was observed near *Clooney*, in the County of Sligo. In the year 1839, 40·5 inches fell at Toomavara, County of Tipperary, whilst only 21·7 inches fell at Armagh, and 21·796 inches in Suffolk, *during the same year.*

The mean temperature in the *North* of *Ireland* is 48° *Fahrenheit;* in the middle 50°; and in the South, 52°. The quantity of rain which annually falls, as deduced from observations of different authorities, for a stated number of years, is as follows:

Locality.	Authority.	Aver. of Years.	Quantity in inches.
Dublin,	Apjohn,	6	30·87
Belfast,	Portlock,	6	34·96
Castlecomer,	Aher,	18	37·80
Cork,	Smith	6	40·20
Cork,	Royal Inst.	6	36·03
Derry,	Sampson,	7	31·12

From whence it appears, that *Dublin* is the driest, and *Cork* the wettest of those localities in which observations have been made.

From accurate observations it has been ascertained, that the proportion of rain falling during the several months of the year in Pisa, Upminster, and Zurich, was :

	Depth at				Depth at		
Months.	Pisa, in inches.	Upminster, in inches.	Zurich, in inches.	Months.	Pisa, in inches.	Upminster, in inches.	Zurich, in inches.
Janu.	6·41	2·88	1·64	July	0·00	1·11	3·50
Feb.	3·28	0·46	1·65	August	2·27	2·94	3·15
March	2·65	2·03	1·51	Sept.	7·21	1·46	3·02
April	1·25	0·96	4·69	Oct.	5·33	0·23	2·44
May	3·33	2·02	1·91	Nov.	0·13	0·86	0·62
June	4·90	2·32	5·91	Dec.	0·00	1·97	2·62
Half-yr	21·82	10·67	17·31	Half-yr	14·94	8·57	15·35

It may also be interesting and useful to know the results ascertained for the following places:

Petersburgh,	16	inches.	Keswick,	67·5
Greneda,	126	„	Kendal,	59·8
Calcutta,	81	„	Liverpool,	34·4
Average for England,	31	„	Manchester,	33·0
London,	23	„	Bristol,	29·2

For further observations on this inexhaustible subject, see Philosophical Transactions, abridged, volume 4th, pages 2, and 81, &c., and also Meteorological Journal of the Royal Society, published annually in the Philosophical Transactions.

The quantity of rain water that annually falls in these countries has been variously estimated, but generally ranges from 32 to 33 inches deep ; and it is known that the greatest fall in twenty-four consecutive hours does not exceed 1½ inches, and it is a generally received opinion that one-third thereof, or half an inch only, enters the rivers in the same space of time. As this is an important point to have settled, I beg leave here to insert Mr. Mac Mahon's interesting remarks on the subject, taken from his elaborate report on the Drainage and Navigation of the Lough Neagh district, he says, page 41, "To carry out the orders of the Admiralty, with reference to the rise and fall of floods. Captain Mudge selected two central points on the shores of Lough Neagh, one near Langford Lodge on the east, and the other at Arboa point on the west, where he erected his flood gauges, and established his offices for registering the variation in the heights of the water; these observations were carried on with great attention, and particularly from the 19th of November, 1831, to 30th July, 1832.

"Registries were also kept during a part of the past and present year, 1846, by order of the Drainage Commissioners, at Toome Bridge, Lower Bann River, Ellis' Gut, Lagan Navigation, Newry Canal, and Charlemount. These notations were carried on in connexion with the other preliminary enquiries incidental to the investigation then in progress.

"On a careful examination and comparison of the whole of the tables resulting from these registries, we find that the greatest rise of the waters of the lake, uninfluenced by the wind, does not exceed four and a-half inches in twenty-four hours, and there is no record of any continuance of such rise for any successive number of days; thus, the greatest elevation the waters attained in any one month during the examination referred to, did not exceed sixteen inches, but a period of thirty consecutive days may be selected, in which the floods rose twenty-eight inches (viz., between the 19th November and 19th December, 1831), and of this height, half was attained in the first five successive days; but as the waters fell for several subsequent days, the whole period of thirty days elapsed before they reached the height of twenty-eight inches already adverted to. Now, the waters of 1865 square miles, *vide* page 42, or of 1,193,600 statute acres of which the lough itself contains 98,235, or nearly one-twelfth the area of the catchment basin, enter Lough Neagh.

Having ascertained, from the rain-gauge registries kept in the district, that 1½ inches in depth of rain, on the surface of the land, occasionally falls in twenty-four consecutive hours; if we adopt the generally received opinion that ⅓ of this quantity, in cases of extended catchments, which, on the whole area of this basin is equal to 2,166,396,000 cubic feet, is discharged superficially by the rivers and streams into the sea, we arrive at the conclusion that, should this quantity pass into the lake, in the space of time that the rain-gauges denote is allotted to its fall from the Heavens, we would have the surface of this great reservoir raised upwards of *six* inches, notwithstanding the discharge by the Lower Bann River, which may be taken in summer at 100,000 cubic feet per minute.

"Captain Mudge's registry gives the observed maximum flood rise, on the surface of the Lough in twenty-four consecutive hours, at 4½ inches; this rise contains a quantity of water equal to 1,604,691,226 feet long, 561,704,776 cubic feet less than the result which should be produced by half an inch, or one-third of the rain that falls in twenty-four hours on the whole catchment basin, if delivered in that time into the lake. In the mode we adopt here of accounting for the difference, we, in my mind, give the most satisfactory evidence of the accuracy with which the registries have been kept, as well as the justness of the theoretic principles which assign a limit to the quantity of rain that falls within a given time, and its distribution after it has fallen.

"In this case, a great portion of the catchment basin is very little raised above the level of the lake. The rain consequently flows slowly off it; and the more elevated parts being the most remote, the surplus waters arising from the great fall adverted to require a greater length of time than twenty-four hours for their passage to the lough—to which may be added, the loss from evaporation and absorption, being from these causes greater. It can be readily conceived, that the floods in the lake do not rise to the extent due to the fall of rain on the whole catchment basin, but in proportion to the quantity which finds its way into this recipient, within a limited time."

Although the foregoing arguments and proofs are conclusive as far as the observations on Lough Neagh have been made, still many other circumstances tend to alter the quantity of water flowing into rivers during twenty-four consecutive hours in the rainy season; such as the adjacent land being of a low, wet, or swampy nature; or previously saturated by slight falls of rain; or dried up by long continued drought, which renders the surface of the earth so dry and hard as to be impervious to rain recently fallen; add to this, the circumstance of the land having a considerable, and frequently precipitous fall: in such cases the waters will descend to the rivers in greater quantities, or shorter intervals than usual, or than they would under opposite circumstances.

SECTION III.

OF CATCHMENT BASINS.

It is requisite, and obviously of the greatest importance, that the Engineer should study the nature of the soil, climate, situation of the land, or any other circumstance that may enable him to arrive at the quantity of water he will have to provide for, with a view of making suitable channels or conduits for its reception and discharge in times of maximum floods. To enable him to calculate the quantity of water he may expect, it will be desirable that he should be provided with a good map of the country or district, having the contour thereof accurately delineated thereon.

Those maps of Ireland, showing the *physical* features and *geological* structure of the country, which were prepared and engraved under the able superintendence of Captain LARCOM and RICHARD GRIFFITH, Esq., gentlemen of the greatest experience, ability, and research, and now Commissioners of Public Works in Ireland, are admirably adapted to the purpose, from the superiority of their execution, and the remarkable accuracy of their minutest details: by their help, the Engineer can readily point out and calculate accurately the number of acres or square miles which contribute their surplus waters to any river, portion of a river, or tributary; and this is what is usually termed their *catchment basin*, or in other words, the catchment basin of any river or tributary is the number of acres or square miles unwatered by it, or whose surplus waters enter it in times of flood.

On these plans you can readily trace the limits of each district. Commencing at the source, find the number of square miles unwatered by that portion of the stream which will be its catchment basin, then at the junction of the next tributary find the extent of its catchment basin, which added to the former will be the catchment basin of both, and thus proceed, adding the catchment basin of each succeeding tributary at its confluence, until you have taken in all.—*Vide* fig. 1st, where the dotted line shows the extent and boundary of each *catchment basin.* Thus at A. the catchment basin is 10 square miles, at the next tributary, B. 16, and so on to the catchment basin at H. where it is supposed to be joined by the River Cashen, amounts to 120 square miles.

The rivers in Ireland are very numerous, for Mr. FRASER, in his Hand-book, enumerates and describes no less than 172 of them, of which the principal is the SHANNON, 159 miles long, from *Lough Allen* to *Limerick*, where it expands into an estuary of forty-five miles, opening into the Atlantic Ocean at Loup Head. It is navigable for nearly the entire of its course.

The Suir, Barrow, Nore, Blackwater, Slaney, Boyne, Foyle, Erne, Lee, Bandon, Bann, and Moy, are all navigable to a greater or less extent.

Many smaller Rivers, serving chiefly for agricultural and domestic purposes, are to be met with in every district, and are now being greatly improved under directions of the BOARD OF PUBLIC WORKS.

The extent of country which forms the Basin of each of the principal rivers, is in *square miles*, as follows:

	C. Basin, in sqr. miles.		C. Basin, in sqr. miles.
Shannon	4,544	Slaney	815
Barrow, Nore, and Suir	3,400	Lee	735
Galway — including Loughs Corrib and Mask	1,374	Liffey	568
Erne	1,585	Blackwater, North	526
Foyle	1,476	Maine and Inney	511
Bann and Maine	1,266	Feal and Gale	479
Blackwater, South	1,219	Roughty	475
Boyne and Blackwater	1,086	Ovoca	281
Moy	1,033	Bandon	228
		Lagan	227
		Avonmore	200

SECTION IV.

HOW TO DETERMINE THE NUMBER OF CUBIC FEET, PER MINUTE, ANY CATCHMENT BASIN WILL YIELD IN TIMES OF FLOOD.

The number of acres or square miles in a catchment basin being thus ascertained, you can easily calculate the number of cubic feet per minute which it may be expected to yield in times of flood; thus half an inch of water on a statute acre, gives 1815 cubic feet, and that multiplied by the number of acres in the entire catchment basin, and divided by 1440, the number of minutes in twenty-four hours, the quotient will be the discharge per minute, suitable to that catchment basin; or, the number of acres in any catchment basin, encreased by the ¼ thereof will be the discharge per minute, thus :

Required, the discharge per minute from 500 statute acres,

1815 Cubic Feet for 1 Acre.
500

1440)907500 = 630 per Min.

Or thus,
500
¼ = 125

625 Ft. per min.

which is sufficiently near for practical purposes, and the Rule that should be *generally* practised.

When the catchment basin is given in square miles, multiply the number by 807, or, for simplicity, by 800, and the product will be the discharge per minute for that catchment basin.

Example I.—What is the discharge, per minute, from a catchment basin of 50 square miles?

50 or 500
807 by 800
Cubic feet 40,350   40,000 cubic feet differing very little from the other, and is the Rule that should be *generally* adopted.

Should the Engineer, from his local knowledge of the situation of the catchment basin, be of opinion that a greater or less amount of the rain fallen in twenty-four consecutive hours enters the rivers, or that a greater or less quantity of rain falls in that time, or than has been already stated, we have, to meet such cases, calculated Table No. 1, which shows the discharge per minute for any assignable portion of the quantity fallen, thus for example:

What would the discharge per minute be for 57·6 square miles, supposing that ·8 of an inch enters the rivers in 24 consecutive hours.

50·0 and ·8 give	64,500
7·0 and ·8 give	9,030
·6 and ·8 give	774
Total discharge	74,304 cubic feet per min.

Example II.—What will be the discharge per minute from a thorough-drained farm of 125 acres, supposing ·9 of an inch passes into the rivers in 24 consecutive hours.

100 by ·9 gives	225
20 by ·9 gives	45
5 by ·9 gives	11·25
Total, in cubic feet, per min.	281·25

Should the proportion of waters entering the rivers, and the time, both vary from those quantities stated, they can be reduced by the following simple statement, thus:

If ·9 of an inch enter the river in 36 hours, what is that per 24 hours? Say as 36 : .9 : : 24 : .6 the quantity which would enter in 24 hours.

And in the same manner may be found the discharge per minute, for any number of acres or square miles of catchment basin.

Table No. 1. is only calculated from ·1 of a sqr. mile to 10 square miles, but the discharge may easily be found for ten, or one hundred times that number, by adding a cypher or two to the discharge shown by the Table, thus the discharge for 100 square miles, at ·6 of an inch, is 96,800 cubic feet per minute, viz., that for 10 square miles increased tenfold, and so with the Table, on the same page, for acres, which is particularly adapted for "Thorough Drainage," as it will enable the Landlord, Agent, or Occupier, by simple inspection, to ascertain the quantity of water that must be discharged from his farm or holding per minute, in time of maximum floods. Hereafter a *Table* will be given for finding the dimensions of a pipe, conduit, main drain or channel, for its discharge, As the *velocity* and *times* of descent of the waters from the catchment basins will always be influenced by the height of the adjacent mountains, it may be useful to give the following interesting Table of the *altitudes* of the principal *Irish Mountains*, from Mr. Griffith's Geological Report:

ALTITUDE OF IRISH MOUNTAINS.

	Feet.		Feet.
	MUNSTER.		
Keeper	2265	Brandon	3120
Devil's Bit	1572	Gurrane Tual	3104
Slievenaman	2362	Mangerton	2754
Galtymore	3008	Mount Gabriel	1335
Craig	1715	Cahirfarna	2234
Knockaness	1305	Sheehy	1796
Callan	1288	Hungary Hill	2248
Knockfierna	937	The Paps	2280
Seefin	1706	Monavullagh	2598
	LEINSTER.		
Carnclonhugh	912	Lugnaquilia	3039
Carlingford	1935	Mount Leinster	2604
Ravensdale	1674	Slivebloom	1689
Kippure	2473	Arden Erin	1689
Great Sugar-loaf	1651	Brandon	1696
	ULSTER.		
Knocklayd	1685	Slievesnaght (east)	2019
Throstan	1810	Bluestack	2213
Slemish	1437	Slievedonard	2796
Divis	1568	Slievebingian	2449
Sawel	2236	Eagle Mountain	2084
Bendbradah	1531	Slievecroob	1755
Carntogher	1521	Slievegullion	1893
Slievegallion	1730	Belmore	1312
Erigal	2462	Carnmore	1034
Muckish	2190	Cuilcagh	2188
	CONNAUGHT.		
Benbo	1365	Benbulbin	1697
Lackagh	1448	Nephin	2639
Slieveanierin	1922	Croaghpatrick	2499
Truskmore	2113	Mulirea	2680
Slievebon (north)	839	Twelvepins, Binabola	2396
Do. (south)	857	Beinnacoire	2337

SECTION V.

OF THE PROPER FORM OF CHANNELS AND THE VELOCITY OF WATER IN THEM.

Before proceeding farther, it may be desirable to notice the most suitable form for the channels or beds of Rivers, and, from the former considerations on the Hydraulic mean depth of Rivers, it would appear evident, that the form which offers the least resistance, in point of friction, and which would give the greatest Hydraulic mean depth, should be the most favourable, and this form is peculiarly the property of the *circle*, as it contains the greatest area within the least compass, and therefore, of all transverse sections of a River, having the same area, the semi-circular would have the least perimeter or border, and its Hydraulic mean depth, equal to half the radius; but, notwithstanding this apparent advantage of the circular bed, it is not difficult to perceive that it is incompatible with a due regard to the *regimen* of the stream or stability of its banks, and could only be used with advantage in *artificial* works, such as Culverts, Conduit pipes, &c., as the banks of a circular bed would soon be undermined and tumble down, and, being dissolved in the water, would be carried along and deposited where the ocean or other obstruction may check its speed: similar events would constantly recur, until nature had eventually formed a bed, permanent and suitable to her necessities.

Slopes of one to one are found sometimes too steep for the banks of rivers, although they have been selected for their simplicity in the construction and calculation of Table 2nd, as being suitable and less liable to objection than any other.

But it has been observed, that the spontaneous efforts of mysterious nature frequently slope the banks in a ratio of 4 to 3, which is known to stand very well, and is the slope usually given, especially in the higher and steeper grounds.

For a rectangular Conduit or Mill-race, the best form would be, that, whose height is half the breadth, or a square bisected parallel to one of its sides; and the best form of a trapezoid will be when its bottom breadth is two-thirds of the depth, and its extreme breadth at surface $3\frac{1}{3}$ its vertical depth. The knowledge of which may be useful to those about to erect mills or construct water courses for supplying cities or large towns, both for its economy and efficiency.

We shall, in next Section, show how to find the area of the *transverse section* of a River, its *hydraulic mean depth*, its *mean velocity*, and ultimately, its *expense or discharge*, per minute, in cubic feet, both in Rivers and over Weirs, with stated declivities; and, also, conversely ascertain the dimensions suited to the discharge of a given quantity in a given time, with any given declivity or inclination; for the better comprehending of which the following DEFINITIONS will be found of considerable use to the *uninitiated*, for whose information the work is principally intended:

The *Sectional Area* of any River, Stream, or Aqueduct, is the number of square feet or inches in that vertical section of it which is at right angles to the direct course of the stream.

The *Hydraulic Mean depth*, is the depth that a River, Canal, &c., would have, if it flowed in a new channel having vertical sides, and flat bottom equal to the perimeter or sum of the sides and bottom of the *real* channel.

The *Border* of a River, Canal, &c., is the sum of the sides and bottom, or it is the perimeter in *contact* with the water. The *declivity*, or rate of inclination of a River is the fall or descent in a given distance, and is usually stated in feet or inches per mile.

The *velocity* of a River, stream, &c., at the top is usually called its *superficial velocity;* that at the bottom, its *bottom velocity*; and that which is an arithmetical mean between each, is the *mean velocity;* and this is the velocity which regulates the *Train*, the *discharge*, the effect on *Machines*, and all the other important consequences arising from its great mechanical agency as a motive power.

The greatest velocity of a River is at its surface, and in the middle of the stream, from which it diminishes towards the bottom and sides, where it is least. This velocity in the middle of a stream may be ascertained by observing the *distance* which a floating body passes over in a *given time.*

When the water in a River is increased by the junction of a tributary or other permanent addition, the velocity of the entire mass is increased, which causes an additional increase of action on the sides and bottom, from which circumstance the breadth of the bottom will invariably be enlarged, and this increased action on the bed of the River will be diminished only when the hardness of its bed, or the tenacity of the soil affords sufficient resistance, and hence the change which frequently takes place in the beds of Rivers.

The mean velocity may be also deduced from the observed superficial velocity, thus :

Let $V =$ the superficial velocity, then will the *mean velocity* $= V - \sqrt{V} + \frac{1}{2}$, and the bottom velocity $\overline{\sqrt{V}-1}|^2$.

RULE.—Take unity from the square root of the superficial velocity, the square of the remainder will be the velocity at *bottom*, and the *mean* velocity is half the sum of these two velocities ; thus, for

EXAMPLE.

If the superficial velocity of a stream per second, be 25 inches, what is the mean velocity ?

$\sqrt{25} = 5 - 1 = 4$ and $4^2 = 16$ the velocity at bottom.

The mean $= \frac{25+16}{2} = 20\frac{1}{2}$ per second, or 1230 ft. per minute.

To ascertain this mean velocity is of the utmost importance, as from it and the sectional area we deduce the expense or discharge; but its particular place in the stream cannot be ascertained. In moderate velocities it is more than one-fourth of the depth distant from the bottom, and in very great velocities it was found to be much higher, but never in the middle of the depth; but as the superficial velocity is easily observed, the mean velocity as has been already shown can be readily computed. Table 6th will save much time and trouble as it shows at a glance the mean velocity in feet, per minute, and also the superficial and bottom velocities.

The knowledge of the velocity at the bottom is of great importance, as it enables us to to judge of the action of the stream on its bed; for every kind of soil has a particular velocity, consistent with the stability of the channel. A greater velocity would cause the water to tear it up, and a less velocity would permit the deposition of moveable material on the bottom.

It is sufficient for the stability of a River that the accelerating forces of its waters are so adjusted to the size and figure of the channel, that the current may be in *train* and also in equilibrio with the tenacity of the soil.

From observations made on the beds of Rivers, it was found that a velocity of 15 feet per minute at bottom will just begin to operate on very fine clay, and will tear it up, however tenacious it may be;

and yet no beds are more stable than clay, when the velocity does not exceed this; for the waters soon take away the impalpable particles, leaving the larger particles of sand sticking by their lower half in the rest of the clay, which they now protect by making a very permanent bottom, if the stream does not bring down gravel or coarse sand which will rub off this thin crust and allow another layer of particles to be worn off. A velocity of 30 feet per minute will lift fine sand, and 40 feet will lift sand as coarse as linseed, 60 feet per minute will sweep away fine gravel, and double that velocity rolls round pebbles an inch in diameter, and treble it will sweep along angular stones two inches in diameter.

SECTION VI.

INVESTIGATION OF THE FORMULA USED IN THE CONSTRUCTION OF TABLE NO. 2.

This TABLE shows, by inspection, the discharge in cubic feet, per minute, of any river, channel, drain, or canal. It commences with 2 feet bottom, and increases by 2 feet, until the bottom breath amounts to 40 feet, and the depths commence with 1 foot and increase by 3 inches, until they amount to 3 feet 9 inches; and these dimensions are accommodated to every fall per mile from 1 to 10 feet. The corresponding velocity for each fall per mile, and given depth of water, will be found at the bottom of each column of depth; the sides of conducts are calculated to slopes of 1 to 1, by this TABLE, and *auxilary*

TABLES 3 and 4. The discharge for any channel may be found, likewise the slope, dimensions of bottom, depth, and velocity of the water, and many other useful results. Let ABCD (figure 2) be the cross section of a river in the form of a trapezoid, having side slopes* of 1 to 1, let the bottom or base B C, be equal to B, and the height or depth of water B E equal to h, let f equal the fall per *English* mile, and D the discharge, in *cubic feet per minute*, due to this section and fall per mile. The slope being 1 to 1, AE is therefore equal to BE, and AB^2 equal to $AE^2 + BE^2$, *i. e.* equal to $2h^2$, AB is therefore $= \sqrt{2h^2}$, and $AB + CD = 2\sqrt{2h^2} = h\sqrt{8}$, to which add the bottom breadth B, and we have $AB + BC + CD$, or the line ABCD, which is generally termed "*the border or radius of the river*," equal to $h\sqrt{8} + B$, from which we have an easy *rule* for ascertaining the border. When the side slopes are 1 to 1, thus—

Multiply 2.828 *(the square root of* 8*) by the height, and add the bottom breadth to the product, and the sum will be the border.*

EXAMPLE 1.—What is the border or surface in contact with a stream, whose depth is 6 feet, and breadth at bottom 30 feet, with side slopes of 1 to 1?

Here 2.828 $= \sqrt{8}$
Multiplied by 6 the depth
16.968
Bottom = 30
Feet 46.968 = the *Border* or line ABCD.

---

* When the slopes of rivers are not expressed, 1 to 1 is understood.

The sectional area is equal to $(B + h) \,.\, h$, which, divided by the border $h\sqrt{8} + B$ gives $\frac{(B + h)\,.\,h}{h\sqrt{8} + B}$ *the hydraulic mean depth.*

And this hydraulic mean depth is a material *function* or *co-efficient* of the *mean velocity* of the stream, and the mean velocity is such, that if the whole stream moved therewith, it would give the same discharge, as results from the compound motion of its parts (*vide* p. 29), and is found thus—

Multiply the hydraulic mean depth by twice the fall per mile, and the square root of the product, multiplied by .9166[*] *will give the mean velocity of the stream per second.*

Thus— $\frac{\overline{B + h}\,.\,h}{h\sqrt{8} + B}$ the hydraulic mean depth, multiplied by $2f$, and the square root taken gives— $\sqrt{2f \times \frac{(B+h)\,.\,h}{h\sqrt{8} + B}}$ which multiplied by .9166′ will give the mean velocity per second, that the water acquires, and maintains in its channel, and this mean velocity multiplied again by 60 will give—

$55\sqrt{2f.\,\frac{(B+h)\,.\,h}{h\sqrt{8} + B}}$, the *mean velocity of the River in cubic feet per minute.*

Example 2.—Required the *mean velocity* per minute of a river or stream 20 feet broad, 3 feet deep, with a fall 7 feet per mile?

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[*] This co-efficient .9166′ or nearly .92 was deduced by *De Buât*, from a vast number of experiments, on the nature of the resistance which water sustains in its motion through its channel.

Bottom $20 + 3 = 23 \times 3 = 69$ the sectional area of the river.
$2.828 = \sqrt{8}$
3 depth

8.484
20 = bottom

Border 28.484) 69 = 2.4224 hyd. M. depth,
Multiplied by $14 = 7$ ft. fall $\times$ 2.

$\sqrt{33.9136} = 5.8236 \times 55$
$(= .9166 \times 60) = 320.298$ the mean velocity per minute.

The mean velocity having been found, multiply it by the *sectional area*, and it will give the *discharge* in cubic feet per minute, thus:

$$\sqrt{2f \cdot \frac{(B+h) \cdot h}{h\sqrt{8}+B}} \times 55 \times \overline{Bh + h^2} = \sqrt{2f \times 55^2} \times$$

$$\sqrt{\frac{(B+h) \cdot h}{h\sqrt{8}+B}} \times \overline{B + h} \cdot h = 55\sqrt{2f}\sqrt{\frac{\overline{Bh + h^2}/^3}{h\sqrt{8}+B}} =$$

$$55\sqrt{2f \cdot \frac{(Bh+h^2)^3}{h\sqrt{8}+B}} = D$$

the discharge per minute in cubic feet, and affords the following

RULE.

Divide the cube of the sectional area by the border, and multiply the quotient by twice the fall in feet per mile, and 55 times the square root of the product will be the discharge per minute, in cubic feet, all the dimensions being feet.

EXAMPLE 3.—The sectional area in the last example was 69 feet, and border 28.484 feet; we have, therefore,

$$55\sqrt{\frac{69^3 \times 14}{28.484}} = 55 \times 69\sqrt{\frac{69 \times 14}{28.484}} = 22.100 \text{ cub. feet,}$$

the discharge per minute, from a river of that sectional area and fall per mile: or the velocity found in example No. 2, viz.,

320.298 per min.
Multiplied by 69 sec. area

Will be 22,100 the discharge as before.

THE SAME PERFORMED BY LOGARITHMS.

As these calculations are frequently very tedious and laborious, it will greatly simplify the operation and expedite the work, by using Logarithms in place of the ordinary numbers. Thus, to perform the foregoing example :—

Add three times the log. of the sectional area,
,, *The log. of twice the fall per mile,*
,, *The log. arithmetical complement of the border,*
And the constant log. 3.4807254 *;*
And half their sum will be the log. of the discharge in cubic feet per minute.

Example 4.—Let the dimensions be, as in the former case:

Three times the log. of 69 = the sectional area	5.5165473
The log. of 14 = twice the fall per mile	1.1461280
The arithmetical log. compt. of the border 28.484	−2.5453990
The constant log. of 55^2. = 3025	3.4807254
Sum ½)	8.6887997
The Log. of discharge, as before, 22,100 cubic feet	4.3443998

And this is the mode in which Hydraulic Table No. 2, with the several falls per mile, has been calculated ; in which table, under the head of 7 feet fall per mile, and corresponding to 20 feet bottom, and 3 feet deep, will be found 22,100, the discharge in cubic feet per minute, as already calculated ; which shows at once the utility and expedition of this Table.

GENERAL RULES FOR FINDING THE DISCHARGE OF ANY TRAPEZOIDAL OR RECTANGULAR CONDUIT.

As cases will frequently arise in which it may be desirable to use other side slopes than these of 1 to 1, the following *formula* may be then used, the same letters still representing their respective parts : r = the ratio of slopes and $n = .9166'$

Then will $rh+B$ = mean breadth of cross section of river, $(rh+B)\,h$ = sectional area, and $2\,h\sqrt{r^2+1}+B$ = the border, and the hydraulic mean depth will be $=\dfrac{(rh+B)\,.\,h}{2\,h\sqrt{r^2+1}+B}$, the mean velocity $= n\left(\dfrac{2f.\overline{rh+B}.h}{2h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}}$ which, multiplied by the area, $(r\,h+B)\,.\,h$, gives the discharge per second

$$= n\left(\frac{2fh\ .\ \overline{rh+B}}{2\,h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}}+\overline{rh+B}\ .\ h = n\left(\frac{2fh^3\,(rh+B)^3}{2h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}}$$

= the discharge per second, and $60\times n\left(\dfrac{2fh^3\,(r\,h+B)^3}{2\,h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}}$

$= 60\,n\left(\dfrac{2f\,(rh^2+Bh)^3}{2h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}} = D$, the discharge in cubic feet per minute, in which we have a *general* formula for any trapezoidal, rectangular, or square conduit, let the ratio of side slopes, the fall per mile, the breadth or depth be any numbers whatever, and in words, gives the following

GENERAL RULE.

Multiply the height by the ratio of the side slope, and add the base to the product, then multiply this sum by the height or depth of water, and the cube of this product multiplied by twice the fall per mile, and divided by the base plus twice the height multiplied by the square root of the square of the ratio plus 1, *and the square root of the quotient multiplied by* 55, *will be the discharge in cubic feet per minute, all the dimensions being in feet.*

EXAMPLE 5.—What would be the discharge per minute of a river having 12 feet 6 inches fall per mile, if the bottom breadth be 20 feet and depth 10 feet, with side slopes of 2 to 1?

$r = 2$ the ratio of side slope
2

$4 + 1 = 5\ \&\ \sqrt{5} =$ 2,236
$h = 10\times 2 =$ 20

44.72
Breadth 20

Sum 64.72 = border.

$10\times 2 = 20 + 20 = 40\times 10 = 400$ = sectional area of river.

Now $400^3 = 64,000,000 \times 25 = (12\frac{1}{2} \times 2) =$ twice the fall per mile, gives 1600,000,000, which, divided by the border and the square root taken, will be $= \sqrt{\frac{1600,000,000}{64.72}} \times 55 =$ discharge per minute $= \frac{40.000 \times 55}{8,022} = 274,245$ cubic feet per minute.

But, the discharge by the same channel, with side slopes of 1 to 1, would be 208,072 cubic feet per minute, differing, in consequence of the slope, from the former by 66,173 cubic feet, being upwards of 1100 per second. As slopes of 1½ to 1 are frequently required, the discharge will be obtained from them near enough for practice by the following

Rule.—*Multiply half square of the depth of the river by the velocity corresponding to it and the fall per mile, as shown in Table No. 2, at the bottom, under each depth and fall per mile, and the result* ADDED *to the discharge shown by the Table will give the discharge required.*

Thus: should the discharge for a river, with side slopes of 1½ to 1, and bottom 20 feet, depth 3 feet 6 inches, and 5 feet fall per mile be required, we have, by the Table No. 2, the discharge 23,727 cubic feet, and a velocity of 290 feet per minute, which, multiplied by $\frac{\overline{3.6}^2}{2} = \frac{12.96 \times 290}{2} = 1776$, and, added to 23,727, gives 25,503 cubic feet the discharge per minute, while the general rule, p. 37, gives 25,276, which shows *it to be sufficiently near* for practical purposes.

SECTION VII.

RULES FOR WATERCOURSES, AQUEDUCTS, MILL-RACES, ETC., HAVING RECTANGULAR SIDES.

In the general equation $60\,n \left(\frac{2fh^3 \,.\, \overline{rh+B}|^3}{2h\sqrt{r^2+1}+B}\right)^{\frac{1}{2}} = \mathrm{D}$ when $r = o$, the sides become vertical, and the conduit rectangular, as in a mill-race, &c.; in which case the expression will become $60\,n\left(\frac{2fh^3B^3}{2h+B}\right)^{\frac{1}{2}}$

$$=60\,nhB\left(\frac{2fhB}{2h+B}\right)^{\frac{1}{2}}=55hB\left(\frac{2fhB}{2h+B}\right)^{\frac{1}{2}}=D,$$

a very useful FORMULA for finding the quantity in a mill-race, acqueduct, or any *rectangular* conduit with any given fall per mile, and affords the following

RULE.—*Multiply the area of the transverse section by twice the fall per mile, and divide the product by the border, or twice the depth added to the bottom breadth, and the square root of the quotient multiplied by 55 times the sectional area will be the discharge in cubic feet per minnte.*

EXAMPLE.—What would be the supply of a *mill* from a rectangular conduit 4 feet broad, 3 feet deep, with 7 feet fall per mile?

6 = twice depth
4 bottom
10 = border

4 bottom
3 depth
12 area of section
14 double the fall per mile.
10)168
$\sqrt{16.8} = 4.1 \times 12 \times 55 = 2706$

The same result nearly may be had from Table No. 2; thus:

RULE.—*Multiply the square of the depth of water by the corresponding velocity, as shown in the Table 2, and* DEDUCT *the product from the discharge in the Table corresponding to the given dimensions, the remainder will be the discharge required.*

Example No. 2, page 34, gives—

320 = vel.
Sqr. of depth 3 = 9
2880

Discharge by table, 5603
Deduct, 2880
The discharge, 2723 c. ft.

When the breadth at bottom is made double the depth, then will $2\,h = B$, and discharge or supply $110h^2(fh)^{\frac{1}{2}}$ per minute, which gives the following

Rule.—*Multiply* 110 *times the square of the height by the square root of the rectangle of the height and fall per mile, and it will give the discharge per minute in cubic feet.*

Example.—What quantity of water will a rectangular mill-race convey with the following dimensions, viz.—6 feet wide, 3 deep, and fall 4 feet per mile, here $h^2 = 9 \times 110 = 990$
$4 \times 3 = 12$ and $\sqrt{12} = 3.464$

The discharge in cubic feet per minute, 3,429.360

This most useful problem may be also performed by the Table sufficiently near, by the following

Rule.—*From the discharge corresponding to the fall and dimensions given find the discharge and velocity, and from this discharge* deduct *the product of the velocity into the square of the depth, and the remainder will be the discharge.*

Example.—The discharge for the above dimensions by the table is 5720 cubic feet,
and gives a vel. of 242 × 9, the sq. of depth, 2178

Nearly as above, 3542 cubic feet.

When $h = \mathrm{B}$ then will the conduit be square, and $\mathrm{D} = 55\,h^2 \left(\frac{2f\,h}{3}\right)^{\frac{1}{2}}$ which case will also be useful to Engineers or Mill-wrights, about to select mill-sites, when land is difficult to be had. For a Semicircular Conduit the *Formula* will be changed to $\frac{5\,h\,n^2}{11}\,(fh)^{\frac{1}{2}} = \mathrm{D}$. where h = radius of the circle, and $n = 3.1416$ the circumference, when rad. is 1 the Hy. mean depth will be $\frac{h}{2}$ or half the radius, which will also be the Hydraulic mean depth for the circle, for in doubling the area we double the Border likewise.

TO FIND WHAT FALL, PER MILE, MUST A GIVEN CONDUIT HAVE TO CONVEY A GIVEN QUANTITY PER MINUTE.

From the general equation—

$$55\sqrt{2f}\left(\frac{\overline{rh^2+h\mathrm{B}}\,|^3}{2h\sqrt{r^2+1}+\mathrm{B}}\right)^{\frac{1}{2}} = \mathrm{D}$$

We get by squaring each side—

$$55^2 \times 2f \times \frac{\overline{rh^2+hB}|^3}{2h\sqrt{r^2+1}+B} = D^2, \text{ and}$$

$$55^2 \times 2f\sqrt{rh^2+hB}|^3 = (2h\sqrt{r^2+1}+B)\,D^2$$

$$\because f = \frac{\overline{2h\sqrt{r^2+1}+B}\,.\,D^2}{2\,(h^2+hB)^3\,55^2} \text{ the fall per mile,}$$

an expression or FORMULA which gives the *fall* per mile requisite for causing the water to be in TRAIN,* or the discharge of any given quantity of water, when the remaining dimensions are given.

This affords a very important Rule, not inferior to any hitherto given, combining all the circumstances of dimension, rate of inclination, and discharge. When the side slopes are 1 to 1 it assumes the form,

$$\frac{(h\sqrt{8}+B)\,D^2}{55^2 \times 2 \times (h^2+hB)^3} = f$$

from which the following Rule is derived :—

MULTIPLY *the square of the discharge per minute by the border, and divide the product by* 6050 *times the cube of the sectional area, the quotient will be the* FALL *per mile.*

EXAMPLE.—What fall per mile must be given to an aqueduct to enable it to convey 13,872 cubic feet per minute to a TOWN, with a bottom of 10 feet, and depth of 3 feet 6 inches, and side slopes of 1 to 1?

Discharge $= 13{,}872^2 = 192432384$
Border 19.898
Sec. area $47.25^3 = 105488.38$
Multiply 6050
638205909

$$\frac{3829019576}{638205909} = 6 \text{ feet fall per mile.}$$

---

* A river or conduit is said to be *in train* when any alteration in its length will cause no diminution of its discharge.

The work will be much expedited by using Logarithms ; thus :—

To the Log. of the ***Border*** 19.898	Log.	1.2988094
Add *twice* the Log. of discharge 13,872	Log.	8.2842782
		9.5830876

And deduct therefrom—

The Log. of 6,050 .	= 3.7817554	
And 3 times the Log. of 47.25	= 5.0232054	
		8.8049608
	Log. of 6 feet =	0.7781278

the fall per mile required. This work may be still further simplified by using the following form :—

Add the Log. of the border .	19.898	=	1.2988094
Twice the Log. of discharge	13,872	=	9.5830876
The Log. arith. comp. of .	6,050	=	–6.2182446
And 3 times Log. arithm. comp. of	47.25	=	–4.9767946
	Log. of 6 feet the fall	=	0.7781268

This and the preceding examples may be tested by the table No. 2, which will give the answers required by mere inspection.

SECTION VIII.

EXPLANATION AND USE OF TABLE, No. II.

In this Table No. 2 there are *six* distinct elements which enter into its combination ; viz. :—

1 The BREADTH of Bottom in *feet ;*
2 The DEPTH of water in *feet* and *inches ;*
3 The FALL per mile in *feet ;*
4 The DISCHARGE in *cubic feet per minute ;*
5 The mean VELOCITY in *feet per minute ;*
6 And the SIDE SLOPES of 1 to 1 constant ;

and any *three* of these being given the others can be found from the Table by inspection ; thus :—

TO FIND THE DISCHARGE AND VELOCITY PER MINUTE.

Look under the given fall per mile for the bottom breadth, in the margin column to the right or left; and for the depth at the top, under the head of *depth of water in feet and inches;* and in the angle of meeting, will be found the discharge in cubic feet, per minute, and the corresponding mean velocity at bottom—for *example*—

	Bottom.	Depth.		Discharge.	Velocity.
Fall per mile 6 feet.	6 feet	3 ft. 0 in.	=	7,185	297
	10 „	3 ft. 6 in.	=	13,872	317
	20 „	2 ft. 6 in.	=	15,499	276
10 feet fall per mile.	10 „	2 ft. 3 in.	=	8,806	339
	20 „	2 ft. 9 in.	=	23,079	369
	36 „	3 ft. 9 in.	=	65,519	425

HALF *the discharge for any fall per mile will be the discharge for* ONE-FOURTH *that fall.** Thus, *half* the discharge for *two* feet fall per mile will give the discharge for *six inches* fall per mile; and

½ do. for 3 feet per mile will be the discharge for 9 inches
½ do. 4 do. per do. . do. 12 inches
½ do. 5 do. per do. . do. 15 inches
½ do. 6 do. per do. . do. 18 inches.

When the fall per mile is greater than those in the table, divide the given fall per mile by 4, 9, 16, 25, or any other square number, and find the discharge for the quotient by the table, and multiply it by the square root of the square divisor, and the product will be the discharge per minute for the given fall.

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* This RULE should be particularly attended to, *as the motion of rivers depend entirely on the slope of the surface.*

Example.—What will be the discharge of a river 10 feet wide at bottom, 3 feet deep, and having a fall of 72 feet per mile?

Here $72 = 9 \times 8$ and $\sqrt{9} \times 8 = 3$ times the discharge for 8 feet fall; now the discharge for 8 feet fall by the table is

12,462 cubic feet
Multiplied by $3 = \sqrt{9}$

the discharge required 37,386 for 72 feet fall.

What would be the discharge from the same river if the fall per mile had been 36 feet?

Here $9\,)\,36 = 4$ which gives 8,812
$\sqrt{9} = 3$

Total discharge = 26,436 cubic feet.

And so proceed for any other fall per mile, greater than these contained in the Tables.

When the given fall per mile exceeds those in the tables, and cannot be divided by any *square* number *exactly*, look to Auxiliary Table No. 4, for the given fall per mile, and multiply the number opposite to it by the discharge found in Auxiliary Table No. 3, corresponding to 1 foot fall per mile, and the product will be the discharge required.

Example.—Required the discharge due to a river 10 feet wide, 4 feet deep, and 25 feet fall per mile, with side slopes of one to one.

The discharge of this river, with 1 foot fall per mile, is, per Auxiliary Table, No. 3, = 7104, and in Auxiliary Table No. 4, opposite 25 feet fall, will be found 5, which, multiplied by 7104, gives the discharge = 35520 cubic feet per minute.

Again, if the dimensions of the river are too great, and cannot be found on Table No. 2, take one-half or one-fourth the respective dimensions, that is, of the breadth and depth of the river, and multiply the discharge corresponding to this one-half or one-fourth, by the multiplier in Auxiliary Table No. 4, or by $n^2 \sqrt{n}$ when n is the divisor, and the product will be the discharge. Thus, had the dimensions of the foregoing river been 80 feet wide and 16 feet deep, take the *quarter* of each, viz., 20 and 4, and find the discharge for these dimensions as before directed, which will be found by Table No. 2, or Auxiliary Table No. 3, and fall 1 foot per mile, 13,184, which, multiplied 160 (the number standing opposite 25 feet, the given fall per mile, and *quadruple* the dimensions), the product 2,109,440 will be the discharge per minute required, and so proceed in similar cases.

The *converse* of this last operation, is to find the dimensions of conduit, when the quantity and fall are given. Let us suppose 2,109,440 cubic feet, per minute, were to be discharged by a conduit having a fall 108 feet, per mile, what would be its dimensions? Here 108 divided by the square number $36 = 3$; therefore, $\sqrt{36}$, or Six times the discharge for 3 feet fall, per mile, will give the discharge for 108 feet fall; therefore $2,109,440 \div 6 = 351,573$, but on examination under the head of 3 feet fall per mile, in Table No. 2, we cannot find so great a number; divide it *again* by 32, and the quotient 10,978 will be the discharge due to *quarter* the required dimensions, for 4 *times the dimensions give* 32 *times the discharge.* Now, seek this 10,978 under 3 feet fall per mile, and you will find it corresponding to 20 feet bottom and 2 feet 6 inches deep. Each of which multiplied by 4 will give the dimensions required, viz., 80 feet wide and 10 feet deep.

If the same quantity were to be discharged by a fall of 10 feet per mile, what would be the dimensions of the river. Divide, as before, by 32, and the quotient will be 65,920, which seek under fall 10 feet per mile, and corresponding to 36 feet bottom and 3 feet 9 inches deep, you will find 65,519 the nearest number to it; therefore these dimensions *quadrupled* will give 144 and 15 feet, the respective bottom and depth required.

Or, divide 2,109,440 by 101,184, (the tabular number in Auxiliary Table No. IV., corresponding to the *given fall* and *quadruple* the dimensions,) and the quotient 20,847 will be the discharge due to *quarter* the dimensions, which look for in Auxiliary Table No. III., and corresponding with ½ of it will be found 18 feet bottom, and 3·9 deep,* and, therefore, 36 and 3·9 would give the entire 20,847, and, consequently quadruple these dimensions will be 144 and 15, as found above by another method.

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* When the river has a very *considerable* breadth in the *proportion* to the *depth,* the hydraulic mean is scarcely varied, and the mean velocity of the entire or half will differ very little.

SECTION IX.

OF WEIRS.

FORMULA FOR FINDING THE DISCHARGE OF WATER OVER WEIRS.

A **WEIR** or **BAR** is a dam erected across a river for raising its waters in order to take off a draft for a a *mill*, or deepen the channel. Figs. 13, 14, and 15 represent the usual forms of a **DAM** or **WEIR**; they are generally constructed of solid masonry or timber, properly fortified with shoars and side-walls. On the top is usually set a strong plank called the *waste-board*, over which the water flows. It should always be truly horizontal, and of a suitable height.

In consequence of the *parabolic* form which the water assumes in passing over a weir, the quantity will be only 2-3rd of that flowing through an equal orifice, the water running at the *full* depth.—*Vide* HUTTON'S Mathematics, by RAMSAY, p. 575.

Let L = length of weir, d = depth and D = discharge, per minute, in cubic feet.

$$\text{Then will } 60 \times \tfrac{2}{3} \times 5{\cdot}34 \sqrt{d^3} \times L = D$$

$$(3) \quad \text{or } 213{\cdot}6 \sqrt{d^3}.\ L = D$$

$$(2) \text{ and } L = \frac{D}{213{\cdot}6 \sqrt{d^3}} \text{ and } \sqrt{d^3} = \frac{D}{L \times 213.6}$$

$$\text{Or } d^3 = \frac{D^2}{\overline{L \times 213.6}|^2}$$

$$(1) \qquad \because d = \left(\frac{D^2}{(\overline{L \times 313.6}|^2)}\right)^{\frac{1}{3}}$$

From which equations the following cases arise :—

To find the quantity of water that will flow over a given weir, or the LENGTH of a weir which will discharge a given quantity per minute with a *given* depth ; and, lastly, with what *depth* a given quantity of water will pass over a given length of weir.

CASE I.—*To find the depth of water on a weir when the discharge and length of the weir are given.*

RULE.—*Divide the square of the discharge in cubic feet, per minute, by* 213·6 *times the length of the weir squared, and the* CUBE *root of the quotient will be the depth of the water.*

EXAMPLE.—Let it be required to discharge 72,500 cubic feet of water over a weir 120 feet long, what depth will it run at ?

$$72.500^2 = \frac{5,256,250,000}{\overline{213{\cdot}6 \times 120}|^2} = \frac{5,256,250,000}{656,999,424} = 8 \ \& \ (8)^{\frac{1}{3}} = 2 \text{ ft.}$$

the depth required.

To resolve this problem by the Table 5th of weirs, divide 72,500 by 120 the length of weir as before, and we have 604, the quantity of cubic feet, which passes over *each* foot of the weir. Look for this quantity under the head discharge per minute in Table No. 5. For finding the discharge over weirs, and opposite to it in the margin will be found 2 feet, the *depth* required. In the same manner the respective depths for the following discharges will be found, supposing the length of the weirs to be respectively as follows :—

Length of Weir.	Discharge per minute.	Depth it will run.
100 feet.	21,360 cubic feet.	1.0 feet.
150 „	15,127 „	2.8 „
200 „	341,760 „	4.0 „
240 „	26,025 „	0.7 „
300 „	22,265 „	0.5 „
400 „	815,600 „	4.5 „

Case II.—*When the quantity in cubic feet, and the depth of water are given, to find the proper* length *of* weir *for its discharge.*

Rule.—*Divide the discharge in cubic feet by the square root of the cube of the depth multiplied by* 213.6, *and the quotient will be the length required.*

Example.—Required the length of weir that will discharge 341,760 cubic feet per minute, when the depth is 4 feet.

Here $\sqrt{4^3} = 8$
213.6
1708.8) 341760
200 Ft. Length of weir required.

To perform this by the table of discharge over weirs, look for the depth in the margin, and for the discharge in the horizontal column, and under 2 will be found 3,417.6, therefore, 200 will give 341,760.

Case III.—*To find the* discharge *per minute when the length of weir and depth are given.*

Rule.—Cube *the depth and extract the square root of the product, and multiply it by* 213.6 *times the length of the weir in feet, and the product will be the discharge per minute.*

Example.—What is the discharge of a weir 4.5 feet deep, and 400 feet long?

$4{\cdot}5^3 = 91.125$ and its square root $= 9.5458$
Length of weir $400 \times 213.6 = 85{,}440$
815,600 cub. ft. per min.

To perform this by the table, look for 4.5 feet, the *depth* of water and opposite to it under 4 feet long, will be found 8156, which, multiplied by 100, or add two decimals, and the product is 815,600, the discharge in cubic feet per minute, as before. Should it be desirable, in the foregoing example, not to allow the water to rise higher than eighteen *inches*, what would be the length of weir. Look for 18 inches, or 1.5 feet in the table, and opposite to it will be found 392.43, the discharge for *one* foot. Divide 72,500 by it, and the quotient, 185 ft. will be the length required to discharge it.

SECTION X.

APPLICATION OF THE FOREGOING RULES TO PRACTICE.

Let the diagram ABCDEFGHL, *figure* No. 1, represent a *River* and its *Tributaries*, and let the *catchment basin* in square miles of each part and gradient be that set down in the following elementary table, with the respective falls per mile, it is required to determine the dimensions of the various parts and gradients of this river, capable of carrying off the maximum flood, supposing the water to be kept *three feet* in general below the surface of the adjacent land for purposes of THOROUGH DRAINAGE.

ELEMENTARY TABLE OF CONDUITS AND RATES OF INCLINATION.

Number of Gradients.	Name of River, or District.	Fall per mile.	Catchment basin in square miles.	Dischrge. per minute per Table I.	DIMENSIONS OF CONDUIT.				Height of adjacent land above surface of river.	
					Depth of water.		Breadth of bottom.			
		Feet.		Cubic feet.	Feet	In.	Feet	In.	Feet	In.
1	A Feal.	10	10	8,070	2	6	8	0	4	6
2	B	12	16	12,912	3	0	8	0	5	0
3	„	20	16	12,912	3	0	6	0	5	6
4	C	8	25	20,175	3	6	14	0	6	0
5	D Brick.	9	45	36,315	3	9	21	0	6	10
6	„	6	45	36,315	3	9	26	0	8	0
7	E	12	70	56,490	3	9	28	0	10	0
8	F	9	86	69,402	4	0	40	0	6	9
9	G Crumpaun.	6	114	91,998	4	0	47	0	7	9
10	H Cashen.	5	120	96,840	5	0	52	0	6	0
11	L Weir.	Level.	124	100,068	2	8	100	0	Breadth of weir.	

In this table the first column denotes the number of gradients from the source; the second column the *name* of the river or district; the third column the fall per mile; the fourth, the number of acres or square miles in the catchment basin *to that* gradient; fifth, the discharge in cubic feet per minute, taken from table No. 1, and .5 discharge; and the eighth the height the surface of land is above the *proposed* surface of the river; the sixth and seventh columns the dimensions of the river, as ascertained by reference to the table; thus—8,070 cubic feet are to be discharged with a fall of 10 feet per mile, which will be effected by a trapezoidal conduit or waterway of 8 feet bottom and 2 feet 6 inches deep, with side slopes of 1 to 1. See table No. 2, under fall 10 feet per mile, and opposite 8 feet bottom and 2 feet 6 in. deep, will be found 8,575 cubic feet, the discharge per minute for these dimensions, and consequently are fully adequate to the discharge of 8,070 cubic feet per minute, the second gradient at B has a catchment basin of 16 square miles, and a fall of 12 feet per mile. Here $12 = 4 \times 3 = \sqrt{4}$ or twice the discharge for 3 feet fall; now under 3 feet fall, in Table No. 2, look for 6,456 *half* the required discharge, and opposite to 8 feet bottom and 3 feet deep will be found 6,329, which, doubled, will give 12,658, the requisite number of cubic feet, therefore, 8 feet bottom by 3 feet deep, will discharge the entire quantity, and thus proceed through each catchment basin and its respective gradients, finding suitable conduits, always paying due regard to the height of the land, as shown in the eighth column, so as to keep the surface of the water *at least* three feet *beneath* the *lowest* surface of the adjacent land, as already noticed, for the more effectual *thorough drainage* thereof.

This, the Author understands, is the general Rule laid down by William T. Mulvany, Esq., one of the Commissioners of *Public Works* in Ireland, a gentleman whose scientific acquirements, judgment, and practical experience must always entitle his opinions to the highest respect and attention.

The manner of selecting the suitable conduits from the tables for any given discharge will readily be seen from the inspection of the following quantities taken from Auxiliary Table No. 3 ; by which it will appear that there are *several* dimensions which will give the same discharge per minute, viz. :—

				Cubic feet.
2	feet bottom and	5 feet deep	will give	3,969
3	„	4 ft. 6 in.	„	3,889
4	„	4 ft. 3 in.	„	4,086
5	„	4 ft.	„	4,174
6	„	3 ft. 9 in.	„	4,269
7	„	3 ft. 6 in.	„	4,251
8	„	3 ft. 3 in.	„	4,172
9	„	3 ft.	„	4,030
11	„	2 ft. 9 in.	„	4,177
13	„	2 ft. 6 in.	„	4,194
15	„	2 ft. 3 in.	„	4,174
18	„	2 ft.	„	4,047

all being nearly the same discharge per minute, these dimensions can be selected which will but allow the surface of the water to be three feet, or *any other required depth* below that of the adjacent land.

HOW TO FIND THE DIMENSIONS OF A NEW CUT OR MILL-RACE TO CONVEY A GIVEN QUANTITY OF WATER.

At F, the catchment basin, is 86 square miles, (*vide* fig. No. 1,) and the discharge per minute 69,402 cubic feet; it is proposed to direct one-third thereof into a *new cut* from *m* to the harbour at P, with an inclination or fall of seven feet per mile. What should be the dimensions of this new cut? By examining column 6 of the Table of Conduits, page 50, under the head of *depth*, it will be observed that the water runs just 4 feet deep at the commencement of the proposed cut, it will therefore be desirable to continue that depth in the cut, or, say 3 feet 9 inches deep. Look for 23,134, the third part of 69,402, under the fall of 7 feet per mile and 3 feet 9 inches deep, and opposite to 14 feet in the margin, will be found 22,577, the nearest discharge to the one required, therefore 14, or say 14½ feet, by 3 feet 9 inches deep, will be the dimensions for conveying the third part of the water as required. The remaining two-thirds, or 46,268 cubic feet, will not now require a channel so large as that in the Table of Conduits, as the quantity of water to be discharged is less—viz., a channel of 30 feet bottom by 3 feet 6 inches deep will answer, as may be seen under the head of 9 feet fall per mile, so that by carrying off one-third of the water in the *new cut*, the dimensions of the old bed might be considerably lessened, as will be seen by comparing the above dimensions with those in the Table of Conduits.

If it were required to erect a MILL at Q, on the 7th gradient below E, where the fall is 12 feet per mile, What must be the dimensions of the *mill-race* to convey *half* the water that passes that point in winter time? By inspection it will be seen that the catchment basin is 70 square miles, and the discharge per minute 56,490 cubic feet, half of which, 28,245, is to be discharged with a fall of 12 feet per mile. Now this discharge is equivalent to twice the discharge of 3 feet fall per mile, as already shown; consequently, by dividing 28,245 by 2 we have 14,123, the discharge per minute with a fall of 3 feet per mile, through the conduit required.

Now, look to table No. 2, under 3 feet fall per mile, and corresponding to 15 feet at bottom and 3 feet 6 inches deep, you will find 14,094—half the sum of the discharges for 14 and 16 feet—which, multiplied by 2, will be 28,188, the quantity required, differing very little from 28,245: so that the above dimensions will be amply sufficient for the conveyance of the water required. If the fall in this mill-course had been only 9 feet per mile, what would be the dimensions required to convey the same quantity of water, viz., 28,245 cubic feet per minute? Under 9 feet fall, in table No. 2, and corresponding to 3 feet 9 inches deep and 16 feet bottom, we will find 28,875, the discharge required. Suppose the water to run 5 feet deep in this *new* cut, what should be the dimensions? Divide 28,245 by 32 and the quotient will be 883, which will be found under 1 ft. 3 in. deep by 3½ bottom, or a little better, and these numbers quadrupled will be the dimensions required—viz., 5 deep and 14 broad. But the water runs in the river at this point only 3 feet 9 inches deep, therefore you must either deepen the *new* cut, or erect a *bar* or weir across the river to cause the water to rise. Let us now consider what ought the height of this *bar* or *weir* be, to raise the water to the depth required—that is 1 foot 3 inches above its present surface (*vide* fig. 14).

Let the present breadth of the river at bottom be 28 feet, or say 30, as the bottom will be now elevated. The question is, how much *below* the *proposed* surface must the bottom of the *new cut* be, that it may discharge the required portion of water, viz., 28,245 c. ft. The fall will *now* be reduced from 12 ft. to 12 — 1.3, the required elevation of the water surface; or 10.75 feet per mile, the square root of which 3.28 divided into 28,254 gives 8,614, which look for in Table No. 2. under fall 1 foot per mile, and 30 feet base. Corresponding to 30 base and 2.3 deep are 7,973 c.feet
to 30 base and 2.6 deep are 9,356 ,,
2)4.9 2)17,329
Feet 2·4½ ft. deep gives 8,664 c. ft.
the quantity required is 8,614 feet. Therefore 2 ft. 4½ in. deep will be, for *practical* purposes, exact enough, and consequently the height of the *bar* or weir will be 5 feet — 2 ft 4½ in. = 2 feet 7½ inches.

To find what depth of water should be on a weir of 100 feet long to discharge the remaining water in the river, look in the Table of Weirs, No. 5, for the discharge, and corresponding to 1.2 feet deep, and 1 foot base, will be found 280.6704 cubic feet, which, multiplied by 100, gives 28,067 the discharge, near enough for *practice;* therefore 1.2 feet will be the depth of water required on the weir.

SECTION XI.

STRAIGHTENING OF RIVERS.

Rivers are seldom straight in their course, formed by the hand of NATURE, they are accommodated to every change of circumstance: they wind round and work their way on either side according to the resistance of the opposite bank makes a *straight* course more difficult. Those rivers are in general the straightest in their course which are most rapid, and which convey the greatest body of water; the small rivers continue more devious in their progress till they approach the SEA, and have collected strength from their *Tributaries*, which enables them to proceed with greater energy and force.

A RIVER 20 feet wide and 3 feet deep with a fall of 2 feet per mile is to be straightened by a *new* cut of the same dimensions at bottom, What will be the depth of water in this new cut supposing the river be made a mile shorter by it? By inspection, in Table No. 2, we find the discharge per minute due to a river twenty feet by three, with a fall of two feet per mile, is 11,813 cubic feet per minute; and, as the *new* river is to be a mile shorter, the fall per mile will be in this new cut four feet. Look under four feet fall per mile for the discharge 11,813, and corresponding to twenty feet base we find the nearest depth is between two feet three inches and two feet six inches; therefore the depth of water, in consequence of the increased velocity, will be reduced six inches at least, and by further inspection it will be seen that 16 feet by 2.9 deep would discharge it in the new channel, thus decreasing both the bottom breadth and depth of water; and should it be required to have it run the same depth as before, it will be seen that 14 feet bottom would discharge it.

OF THE SURFACE OF RIVERS, AND THE CURVES THEY ASSUME.

OF ELBOWS OR BENDS.

It may be observed that the surface of rivers generally assume a *Curve* of the *Hyperbolic* kind, the Convexity being towards the bottom, if the channel has only a small declivity the Curvature of the surface is inconsiderable and may be taken as a right line parallel to the Bottom, and should the Bottom be Horizontal the surface becomes a Horizontal plane also. If the width of the Channel vary, the Curve would be somewhat different, but when the breadth is constant and considerably exceeding the depth, as most frequently happens the curvature of the surface will differ but little from what has already been remarked. It may also be observed that the depth of water must be greater in an *elbow* or bend than elsewhere; for the stream striking against the concave bank will be reflected in the direction of the next course of the river, therefore there must be an increase of slope or head of water in the elbow proportioned to the resistance required to be overcome, although it may be very difficult to ascertain the exact amount thereof. "If we should," says *De Buât*, "attempt to *secure* the permanency of a river by deepening the *inside* of the elbow, our banks will undoubtedly crumble down, diminish the passage, and occasion a more violent action on the hollow bank;" and this is conformable to our daily observations on rivers similarly circumstanced. The *surest* way to guard against a recurrence, is to enlarge on the inside or convex bank considerably, to enable us to have a long sloping bank; but the proper form of an elbow depends on the breadth of the stream, radius of curvature, nature of the soil, and also the position of the angle of the bend, with regard to the direct course of the stream. The formula for determining this resistance will run thus for one rebound $\frac{v^2 s^2}{3000} = r$ wherein v is the mean velocity, s the sine of the angle of incidence, and r the resistance; and as the necessity of overcoming the resistance will increase as the number of rebounds, the general expression will become $\frac{v^2 s^2 n}{m} = r$ where n is the number of *equal* rebounds, that is, having equal angles of incidence, and m a number determined by experiment to be 3200.

TABLE I.—RIVER AND THOROUGH DRAINAGE.

Showing the discharge in Cubic feet, per Minute, for any CATCHMENT BASIN, *in acres and square miles.*

Acres in Basin.	Inch. ·5	Inch. ·6	Inch. ·7	Inch. ·8	Inch. .9	Inch. 1·0	Inch. 1·1	Acres in Basin.
						For Pipes or Tiles.		
1	1·25	1·5	1·75	2·0	2·25	2·5	2·75	1
2	2·50	3·0	3·50	4·0	4·50	5·0	5·50	2
3	3·75	4·5	5·25	6·0	6·75	7·5	8·25	3
4	5·00	6·0	7·00	8·0	9·00	10·0	11·00	4
5	6·25	7·5	8·75	10·0	11·25	12·5	13·75	5
6	7·50	9·0	10.50	12·0	13·50	15·0	16·50	6
7	8·75	10·5	12·25	14·0	15·75	17·5	19·25	7
8	10·00	12·0	14·00	16·0	18·00	20·0	22·00	8
9	11·25	13·5	15·75	18·0	20·25	22·5	24·75	9
10	12·50	15·0	17.50	20·0	22·50	25.0	27·50	10
20	25·00	30·0	35·00	40·0	45·00	50·0	55·00	20
30	37·50	45·0	52·50	60·0	67·50	75·0	82·50	30
40	50·00	60.0	70·00	80·0	90·00	100·0	110·00	40
50	62·50	75·0	87·50	100·0	112·50	125·0	137·50	50
60	75.00	90·0	105·00	120·0	135·00	150·0	165·00	60
70	87·50	105·0	122·50	140.0	157·50	175·0	192·00	70
80	100·00	120·0	140.00	160.0	180·00	200·0	220·00	80
90	112·50	135·0	157·50	180.0	202·50	225·0	247·50	90
100	125·00	150·0	175·00	200·0	225·00	250.0	275·00	100

Square Mls. in Basin.	Inch. ·5	Inch. ·6	Inch. ·7	Inch. ·8	Inch. ·9	Inch. 1·0	Inch. 1·1	Acres in Basin.
0·1	81	97	113	129	145	161	178	64
0·2	162	194	226	258	290	322	356	128
0·3	243	291	339	387	435	483	534	192
0·4	324	388	452	516	580	644	712	256
0·5	405	485	565	645	725	805	890	320
0·6	486	582	678	774	870	966	1,068	384
0·7	567	679	791	903	1,015	1,127	1,246	448
0·8	648	776	904	1,032	1,160	1,288	1,424	512
0·9	729	873	1,017	1,161	1,305	1,449	1,602	576
1·0	807	968	1,130	1,290	1,452	1,613	1,767	640
2·0	1,614	1,936	2,260	2,580	2,904	3,226	3,550	1,280
3·0	2,421	2,904	3,390	3,870	4,356	4,839	5,325	1,920
4·0	3,228	3,872	4,520	5,160	5,808	6,452	7,100	2,560
5·0	4,035	4,840	5,650	6,450	7,260	8,070	8,875	3,200
6·0	4,842	5,808	6,780	7,740	8,712	9,671	10,678	3,840
7·0	5,649	6,776	7,910	9,030	10,164	11,291	12,426	4,480
8·0	6,456	7,744	9,040	10,320	11,616	12,904	14,200	5,120
9·0	7,263	8,712	10,170	11,610	13,068	14,417	15,950	5,760
10·0	8,070	9,680	11,300	12,900	14,520	16,130	17,750	6,400

TABLE II.—SHOWING THE DISCHARGE, IN CUBIC FEET,

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	184	271	375	496	637	795	2
4	336	482	650	841	1,055	1,292	4
6	488	693	925	1,186	1,473	1,789	6
8	640	904	1,200	1,531	1,891	2,286	8
10	792	1,116	1,477	1,875	2,311	2.782	10
12	947	1,332	1,760	2,231	2,745	3,299	12
14	1,102	1,548	2,043	2,587	3,179	3,816	14
16	1,257	1,764	2,326	2,943	3,613	4,333	16
18	1,412	1,980	2,609	3,299	4,047	4,850	18
20	1,567	2,195	2,893	3,656	4,482	5,366	20
22	1,722	2,412	3,178	4,015	4,919	5,887	22
24	1,877	2,629	3,463	4,374	5,356	6,408	24
26	2,032	2,846	3,748	4,733	5,793	6,929	26
28	2,187	3,063	4,033	5,092	6,230	7,450	28
30	2,343	3,279	4,317	5,450	6,669	7,973	30
32	2,498	3,496	4,602	5,809	7,106	8,494	32
34	2,653	3,713	4,887	6,168	7,543	9,015	34
36	2,808	3,930	5,172	6,527	7,980	9,536	36
38	2,963	4,150	5,462	6,887	8,417	10,057	38
40	3,118	4,370	5,752	7,247	9,254	10,578	40
Velocity	74	82	90	96	102	108	in Feet

FALL 2 FEET PER MILE.

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 4 in	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	260	383	530	702	900	1,124	2
4	475	682	919	1,190	1,492	1,827	4
6	690	981	1,308	1,678	2,084	2,530	6
8	905	1,280	1,697	2,166	2,676	3,233	8
10	1,120	1,578	2,088	2,653	3,269	3,935	10
12	1,339	1,883	2,489	3,157	3,883	4,665	12
14	1,558	2,188	2,890	3,661	4,497	5,395	14
16	1,777	2,493	3,291	4,165	5,111	6,125	16
18	1,996	2,798	3,692	4,669	5,725	6,855	18
20	2,215	3,104	4,092	5,172	6,338	7,588	20
22	2,434	3,410	4,506	5,679	6,957	8,326	22
24	2,653	3,716	4,920	6,186	7,576	9,064	24
26	2,872	4,022	5,334	6,693	8,195	9,802	26
28	3,091	4,328	5,748	7,200	8,814	10,540	28
30	3,314	4,637	6,161	7,706	9,432	11,278	30
32	3,533	4,943	6,575	8,213	10,051	12,016	32
34	3,752	5,249	6,989	8,720	10,670	12,754	34
36	3,971	5,555	7,403	9,227	11,289	13,492	36
38	4,190	5,861	7,817	9,734	11,908	14,230	38
40	4,409	6,167	8,231	10,241	12,527	14,968	40
Velocity	106	113	126	136	144	152	in Feet

PER MINUTE, FALL 1 FOOT PER MILE.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	974	1,174	1,395	1,637	1,904	2,193	2
4	1,553	1,838	2,148	2,482	2,843	3,231	4
6	2,132	2,502	2,901	3,327	3,782	4,269	6
8	2,711	3,166	3,654	4,172	4,721	5,307	8
10	3,289	3,830	4,406	5,017	5,663	6,344	10
12	3,892	4,524	5,195	5,909	6,652	7,438	12
14	4,495	5,218	5,984	6,801	7,641	8,532	14
16	5,098	5,912	6,773	7,693	8,630	9,626	16
18	5,701	6,606	7,562	8,585	9,619	10,720	18
20	6,307	7,303	8,353	9,477	10,611	11,817	20
22	6,916	8,005	9,152	10,373	11,615	12,929	22
24	7,525	8,707	9,951	11,269	12,619	14,041	24
26	8,134	9,409	10,750	12,165	13,623	15,153	26
28	8,743	10,111	11,549	13,061	14,627	16,265	28
30	9,356	10,816	12,350	13,957	15,634	17,379	30
32	9,965	11,518	13,153	14,862	16,640	18,493	32
34	10,574	12,220	13,956	15,767	17,648	19,607	34
36	11,184	12,922	14,759	16,672	18,655	20,721	36
38	11,794	12,212	15,562	17,577	19,662	21,835	38
40	12,404	12,922	16,365	18,482	20,669	22,949	40
per	113	117	121	125	130	133	Minute.

FALL 2 FEET PER MILE.

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	1,378	1,661	1,973	2,317	2,693	3,103	2
4	2,196	2,600	3,037	5,511	4,022	4,569	4
6	3,014	3,539	4,101	4,705	5,351	6,036	6
8	3,832	4,478	5,165	5,899	6,680	7,503	8
10	4,651	5,417	6,231	7,095	8,009	8,972	10
12	5,504	6,399	7,347	8,356	9,408	10,520	12
14	6,357	7,381	8,463	9,617	10,807	12,068	14
16	7,210	8,363	9,579	10,878	12,206	13,616	16
18	8,063	9,345	10,695	12,139	13,605	15,164	18
20	8,919	10,328	11,813	13,403	15,006	16,712	20
22	9,781	11,322	12,943	14,670	16,426	18,285	22
24	10,643	12,316	14,073	15,937	17,846	19,858	24
26	11,505	13,310	15,203	17,204	19,266	21,431	26
28	12,367	14,304	16,333	18,471	20,686	23,004	28
30	13,232	15,297	17,466	19,738	22,109	24,578	30
32	14,094	16,291	18,602	20,419	23,532	26,152	32
34	14,956	17,285	19,738	21,100	24,955	27,726	34
36	15,818	18,279	20,874	21,781	26,378	29,300	36
38	16,680	19,273	22,010	22,462	27,801	30,874	38
40	17,542	20,267	23,146	23,143	29,224	32,448	40
per	159	165	171	177	183	190	Minute.

TABLE II.—SHOWING THE DISCHARGE, IN CUBIC FEET,

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6. in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	319	469	649	859	1,101	1,377	2
4	582	835	1,126	1,456	1,829	2,237	4
6	845	1,201	1,603	2,053	2,557	3,097	6
8	1,108	1,567	2,080	2,650	3,285	3,957	8
10	1,372	1,933	2,557	3,249	4,013	4,819	10
12	1,640	2,306	3,048	3,866	4,763	5,714	12
14	1,908	2,689	3,539	4,483	5,513	6,609	14
16	2,176	3,062	4,030	5,100	6,263	7,504	16
18	2,444	3,435	4,521	5,717	7,013	8,399	18
20	2,714	3,802	5,012	6,334	7,763	9,294	20
22	2,982	4,177	5,519	6,955	8,521	10,197	22
24	3,250	4,552	6,026	7,576	9,279	11,100	24
26	3,518	4,927	6,533	8,197	10,037	12,003	26
28	3,786	5,302	7,040	8,818	10,795	12,906	28
30	4,058	5,680	7,546	9,438	11,552	13,809	30
32	4,326	6,055	8,053	10,059	12,310	14,712	32
34	4,594	6,430	8,560	10,680	13,068	15,615	34
36	4,862	6,805	9,067	11,301	13,826	16,718	36
38	5,130	7,180	9,574	11,923	14,584	17,821	38
40	5,398	7,555	10,081	12,544	15,342	18,924	40
Velocity	130	143	155	166	176	186	in Feet,

FALL 4 FEET, PER MILE.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	368	542	750	992	1,274	1,590	2
4	672	964	1,300	1,682	2,110	2,584	4
6	976	1,386	1,850	2,272	2,946	3,578	6
8	1,283	1,808	2,400	3,062	3,782	4,572	8
10	1,584	2,232	2,954	3,750	4,622	5,564	10
12	1,894	2,664	3,520	4,462	5,490	6,598	12
14	2,204	3,096	4,086	5,174	6,358	7,632	14
16	2,514	3,528	4,652	5,886	7,226	8,666	16
18	2,824	3,960	5,218	6,598	8,094	9,700	18
20	3,134	4,390	5,786	7,312	8,964	10,732	20
22	3,444	4,824	6,356	8,030	9,838	11,774	22
24	3,754	5,258	6,926	8,748	10,712	12,816	24
26	4,064	5,692	7,496	9,466	11,586	13,858	26
28	4,374	6,126	8,066	10,184	12,460	14,900	28
30	4,686	6,558	8,634	10,900	13,338	15,946	30
32	4,996	6,992	9,204	11,618	14,212	16,988	32
34	5,306	7,426	9,774	12,336	15,086	18,030	34
36	5,616	7,860	10,344	13,054	15,960	19,072	36
38	5,926	8,294	10,914	13,772	16,840	20,122	38
40	6,236	8,728	11,484	14,490	17,720	21,172	40
Velocity	149	164	180	192	204	216	in Feet,

per Minute, Fall 3 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2f. 6in.	2f. 9in.	3 f.0in.	3f.3.in.	3f.6 in.	3f.9.in.	Feet.
2	1,649	2,034	2,417	2,838	3,299	3,799	2
4	2,661	3,184	3,721	4,301	4,926	5,596	4
6	3,673	4,334	5,025	5,764	6,553	7,393	6
8	4,685	5,484	6,329	7,227	8,180	9,190	8
10	5,696	6,634	7,632	8,690	9,809	10,988	10
12	6,741	7,837	8,999	10,235	11,523	12,884	12
14	7,786	9,040	10,366	11,780	13,237	14,780	14
16	8,831	10,243	11,733	13,325	14,951	16,676	16
18	9,876	11,446	13,100	14,870	16,665	18,512	18
20	10,924	12,649	14,468	16,416	18,378	20,468	20
22	11,980	13,866	15,852	17,968	20,118	22,395	22
24	13,036	15,083	17,236	19,520	21,858	24,322	24
26	14,092	16,300	18,620	21,072	23,598	26,299	26
28	15,148	17,517	20,004	23,624	25,338	28,176	28
30	16,205	18,734	21,391	24,176	27,078	30,102	30
32	17,268	19,951	22,782	25,743	28,819	32,028	32
34	18,331	21,168	24,173	27,310	30,559	33,954	34
36	19,394	22,385	25,564	28,877	32,299	35,880	36
38	20,457	23,602	26,955	30,444	34,039	37,806	38
40	21,520	24,819	28,346	32,011	35,779	39,732	40
per	195	202	210	217	224	234	Minute.

Fall 4 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f.6in.	2 f.9 in.	3 f.0 in.	3 f.3 in.	3 f.6 in.	3 f.9 in.	Feet.
2	1,948	2,348	2,790	3,274	3,809	4,386	2
4	3,106	3,676	4,296	4,964	5,688	6,461	4
6	4,264	5,004	5,720	6,654	7,567	8,536	6
8	5,422	6,332	7,308	8,344	9,446	10,611	8
10	6,578	7,660	8,812	10,034	11,326	12,688	10
12	7,784	9,048	10,390	11,818	13,305	14,877	12
14	8,990	10,436	11,968	13,602	15,284	17,066	14
16	10,196	11,824	13,546	15,386	17,263	19,255	16
18	11,402	13,212	15,124	17,170	19,242	21,444	18
20	12,614	14,606	16,706	18,954	21,222	23,634	20
22	13,832	16,010	18,304	20,746	23,231	25,859	22
24	15,050	17,414	19,902	22,538	25,240	28,084	24
26	16,268	18,818	21,500	24,330	27,249	30,309	26
28	17,486	20,222	23,098	26,122	29,258	32,534	28
30	18,712	21,632	24,700	27,914	31,268	34,758	30
32	19,930	23,036	26,300	29,724	33,278	36,982	32
34	21,148	24,440	27,912	31,534	35,288	39,206	34
26	22,368	25,844	29,518	33,344	37,298	41,430	36
38	23,588	27,248	31,124	35,154	39,308	43,654	38
40	25,808	28,652	32,730	36,964	41,318	45,878	40
per	226	234	242	250	260	266	Minute.

TABLE II.—SHOWING THE DISCHARGE IN CUBIC FEET,

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	410	605	838	1,109	1,422	1,778	2
4	750	1,078	1,454	1,881	2,358	2,889	4
6	1,090	1,551	2,070	2,653	3,294	4,000	6
8	1,430	2,054	2,686	3,425	4,230	5,111	8
10	1,772	2,496	3,303	4,194	5,168	6,222	10
12	2,118	2,978	3,936	4,990	6,138	7,377	12
14	2,464	3,460	4,569	5,786	7,108	8,532	14
16	2,810	3,942	5,202	6,582	8,078	9,687	16
18	3,156	4,424	5,835	7,378	9,048	10,843	18
20	3,503	4,908	6,470	8,176	10,021	12,000	20
22	2,850	5,393	7,124	8,978	10,999	13,165	22
24	4,197	5,878	7,778	9,780	11,977	14,330	24
26	4,544	6,363	8,432	10,582	12,955	15,495	26
28	4,891	6,848	9,086	11,384	13,933	16,660	28
30	5,239	7,333	9,742	12,185	14,913	17,827	30
32	5,586	7,818	10,396	12,987	15,891	18,992	32
34	5,933	8,303	11,050	13,789	16,869	20,157	34
36	6,280	8,788	11,704	14,591	17,847	21,322	36
38	6,627	9,273	12,358	75,393	18,825	22,487	38
40	6,974	9,758	13,012	16,195	19,600	23,652	40
Velocity	167	180	200	215	228	240	in Feet

FALL 6 FEET PER MILE.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	451	663	918	1,215	1,558	1,948	2
4	824	1,181	1,593	2,060	2,584	3,165	4
6	1,197	1,699	2,268	2,905	3,610	4,382	6
8	1,570	2,217	2,943	3,750	4,636	5,599	8
10	1,945	2,734	3,617	4,595	5,662	6,815	10
12	2,323	3,262	4,311	5,467	6,725	8,081	12
14	2,701	3,709	5,005	6,339	7,788	9,347	14
16	3,079	4,318	5,699	7,211	8,851	10,613	16
18	3,457	4,846	6,393	8,083	9,914	11,879	18
20	3,838	5.376	7,087	8,956	10,978	13,144	20
22	4,218	5,907	7,804	9,834	12,049	14,421	22
24	4,598	6,438	8,521	10,712	13,120	15,698	24
26	4,978	6,969	9,238	11,590	14,191	16,975	26
28	5,358	7,500	9,955	12,468	15,262	18,252	28
30	5,740	8,032	10,672	13,348	16,336	19,529	30
32	6,120	8,563	11,389	14,226	17,407	20,806	32
34	6,500	9,094	12,106	15,104	18,478	22,083	34
36	6,880	9,625	12,823	15,982	19,549	23,360	36
38	7,260	10,156	13,540	16,860	20,620	24,637	38
40	7,640	10,687	14,257	17,738	21,691	25,914	40
Velocity	182	196	220	236	259	263	in Feet

per Minute, Fall 5 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	2,179	2,626	3,120	3,664	4,258	4,905	2
4	3,473	4,110	4,803	5,552	6,359	7,225	4
6	4,767	5,594	6,486	7,440	8,460	9,545	6
8	6,061	7,078	8,169	9,328	10,561	11,865	8
10	7,354	8,564	9,852	11,219	12,663	14,186	10
12	8,703	10,018	11,617	13,214	14,876	16,633	12
14	10,052	11,670	13,382	15,209	17,089	19,080	14
16	11,401	13,223	15,147	17,204	19,302	21,527	16
18	12,750	14,776	17,912	19,199	21,515	23,974	18
20	14,103	16,330	18,678	21,193	23,727	26,424	20
22	15,466	17,901	20,465	23,196	25,973	28,911	22
24	16,829	19,472	22,252	25,199	28,219	31,398	24
26	18,192	21,043	24,039	27,202	30,465	33,885	26
28	19,555	22,614	26,826	29,205	32,711	36,372	28
30	20,921	24,186	27,616	31,208	34,958	38,862	30
32	22,284	25,757	29,403	33,201	37,205	41,352	32
34	23,647	27,328	31,190	35,204	39,452	44,842	34
36	25,010	28,899	32,977	37,207	41,699	47,332	36
38	26,373	30,470	34,764	39,213	43,946	49,822	38
40	27,736	32,041	36,551	41,216	46,193	52,312	40
per	251	261	271	281	290	300	Minute.

Fall 6 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	2,387	2,877	3,579	4,014	4,665	5,373	2
4	3,804	4,503	5,382	6,083	6,967	7,915	4
6	5,221	6,129	7,185	8,152	9,269	10,457	6
8	6,638	7,755	8,988	10,221	11,571	12,999	8
10	8,055	9,382	10,793	12,290	13,872	15,540	10
12	9,534	11,083	12,726	14,475	16,296	18,221	12
14	11,013	12,784	14,659	16,660	18,720	20,902	14
16	12,492	14,485	16,592	18,845	21,144	23,583	16
18	13,971	16,186	18,525	21,030	23,568	26,264	18
20	15,499	17,889	20,460	23,215	25,991	28,946	20
22	16,983	19,610	22,318	25,409	28,452	31,671	22
24	18,467	21,331	24,276	27,503	30,913	34,396	24
26	19,951	23,063	26,234	29,697	33,374	37,121	26
28	21,435	24,773	28,192	31,891	35,835	39,846	28
30	22,918	26,495	30,252	34,187	38,295	42,571	30
32	24,402	28,216	32,210	36,381	40,756	45,276	32
34	25,886	29,937	34,168	38,575	43,217	48,021	34
36	27,370	31,658	36,124	40,769	45,678	50,746	36
38	28,854	33,379	38,180	42,963	48,139	53,471	38
40	30,338	35,100	40,136	45,157	50,600	56,196	40
per	276	286	297	307	317	329	Minute.

Table II.—Showing the Discharge, in Cubic Feet,

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	487	716	991	1,312	1,683	2,104	2
4	889	1,275	1,720	2,225	2,791	3,418	4
6	1,291	1,834	2,449	3,138	3,899	4,732	6
8	1,693	2,493	3,178	4,051	5.007	6,046	8
10	2,096	2,953	3,907	4,963	6,115	7,362	10
12	2,505	3,524	4,644	5,905	7,263	8,727	12
14	2,914	4,095	5,381	6,847	8,411	10,092	14
16	3,323	4,666	6,118	7,789	9,559	11,457	16
18	3,732	5,237	6,855	8,731	10,707	12,822	18
20	4,145	5.807	7,592	9,675	11,858	14,197	20
22	4.556	6,381	8,379	10,623	13,015	15,576	22
24	4,967	6,955	9,166	11.571	14,172	16,955	24
26	5,378	7,529	9,953	12,519	15,329	18,334	26
28	5,789	8,103	10,740	13,467	16,486	19,713	28
30	6,200	8,676	11,527	14,418	17,645	21,095	30
32	6,611	9,250	12,314	15.366	18,802	22,474	32
34	7,022	9,824	13,101	16,314	19,959	23,853	34
36	7,433	10,398	13,888	17,262	21,116	25,232	36
38	7,844	10,972	14,675	18,210	22,273	26,611	38
40	8,255	11,546	15,462	19,158	23,430	27,990	40
Velocity	197	211	235	255	270	284	in Feet

Fall 8 Feet per Mile.

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6 in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	520	766	1,060	1,404	1,800	2,248	2
4	950	1,364	1,838	2,380	2,984	3,654	4
6	1,380	1,962	2,616	3,356	5,168	5,060	6
8	1,810	2,560	3,394	4,332	5,352	6,466	8
10	2,240	3,156	4,176	5,306	6,538	7,870	10
12	2,678	3,766	4,978	6,314	7,766	9,330	12
14	3,116	4,376	5,780	7,322	8,994	10,790	14
16	3,554	4,986	6,582	8,330	10,222	12,250	16
18	3,992	5,596	7,384	9,338	11,450	13,710	18
20	4,430	6,208	8,184	10,344	12,676	15,176	20
22	4,869	6,820	9,012	11,358	13,914	16,652	22
24	5,308	7,432	9,840	12,372	15,152	18,128	24
26	5,747	8,044	10,668	13,386	16.390	19,604	26
28	6,186	8,656	11,496	14,400	17,628	21,080	28
30	6,628	9,274	12,322	15,412	18,864	22,556	30
32	7,067	9,886	13,150	16,426	20,102	24,032	32
34	7,506	10,498	14,978	17,440	21,340	25,508	34
36	7,945	11,110	15,806	18,454	22,578	26,984	36
38	8,385	11,722	16,634	19,468	23,816	28,460	38
40	8,825	12,334	17,462	20,482	25,054	29,956	40
Velocity	212	226	252	272	288	304	in Feet

per Minute, Fall 7 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	2,578	3,107	3,692	4,336	5,039	5,804	2
4	4,108	4,862	5,603	6,570	7,525	8,549	4
6	5,638	6,617	7,674	8,804	10,011	11,294	6
8	7,168	8,372	9.665	11,038	12,497	14,039	8
10	8,700	10,133	11,658	13,274	14,983	16,785	10
12	10,297	11,971	13,746	15,634	17,601	19,681	12
14	11,894	13,809	15,834	17,994	20,219	22,577	14
16	13,491	15,647	17,922	20,354	22,839	24,473	16
18	15,088	17,485	20,010	22,714	25,455	28,369	18
20	16,687	19,322	22,100	25,076	28,074	31,266	20
22	18,300	21,181	24,215	27,446	30,732	34,209	22
24	19,913	23,040	26,330	29,816	33,390	37,152	24
26	21,526	24,899	28,445	32,186	36,048	40,095	26
28	23,139	26,758	30,560	34,556	38,706	43,038	28
30	24,754	28,617	32,676	36,926	41,363	45,982	30
32	26,367	30,476	34,791	39,296	44,021	48,925	32
34	27,980	32,335	36,906	41,666	46,679	51,868	34
36	29,593	34,194	39,021	44,036	49,337	54,811	36
38	31,206	35,953	41,136	46,406	51,995	57,754	38
40	32,819	37,712	43,251	48,776	54,653	60,697	40
per	297	310	320	332	342	355	Minute.

Fall 8 Feet per Mile.

Breadth of bottom.	Depth of water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	2,756	3,322	3,946	4,634	5,386	6,204	2
4	4,392	5,200	6,074	7,022	8,044	9,138	4
6	6,028	7,178	8,202	9,410	10,702	12,072	6
8	7,664	8,956	10,330	11,798	13.360	15,006	8
10	9,302	10,834	12,462	14,190	16,018	17,944	10
12	11,008	13,798	14,694	16,712	18,806	21,040	12
14	12,714	14,762	16,926	19,234	21,614	24,136	14
16	14,420	16,736	19,158	21,756	24,412	27,232	16
18	16,126	18,690	21,390	24,278	27,210	30,328	18
20	17,838	20,648	23,626	26,806	30,012	33,424	20
22	19,562	22,644	25,886	29,340	32,852	36,570	22
24	21,286	24,632	28,146	31,874	35,692	39,716	24
26	23,010	26,620	30,406	34,408	38,532	42,862	26
28	24,734	28,608	32,666	36,942	41,372	46,008	28
30	26,464	39,594	34,932	39,476	44,218	49,156	30
32	28,188	32,582	37,204	40,838	47,058	52,292	32
34	29,912	34,570	39,476	42,200	49,898	55,438	34
36	31,636	36,558	41,748	43,562	52,738	58,584	36
38	33,460	38,546	44,020	44,924	55,578	61,730	38
40	35,184	40,534	46,292	45,286	58,418	64,876	40
per	318	330	342	354	366	380	Minute.

TABLE II.—SHOWING THE DISCHARGE, IN CUBIC FEET,

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f.0in.	1 f.3in.	1 f.6in.	1 f 9in.	2 f.0in.	2 f.3in.	Feet.
2	552	812	1,123	1,488	1,911	2,385	2
4	1,008	1,446	1,950	2,523	3,165	3,876	4
6	1,464	2,080	2,777	3,558	4,419	5,367	6
8	1,920	2,714	3,604	4,593	5,673	6,858	8
10	2,377	3,348	4,430	5,625	6,938	8,346	10
12	2,841	3,995	5,272	6,693	8,235	9,897	12
14	3,305	4,642	6,114	7,761	9,537	11,448	14
16	3,769	5,289	6,956	8,829	10,839	12,999	16
18	4,233	5,936	7,798	9,897	12,141	14,550	18
20	4,701	6,585	8,640	10,968	13,446	16,098	20
22	5,166	7,235	9,526	12,045	14,757	17,661	22
24	5,631	7,885	10,412	13,122	16,068	19,224	24
26	6,096	8,535	11,298	14,199	17,379	20,789	26
28	6,561	9,185	12,184	15,276	18,690	22,350	28
30	7,030	9,838	13,070	16,350	20,007	23,919	30
32	7,495	10,488	13,956	17,427	21,318	25,482	32
34	7,960	11,138	14,842	18,504	22,629	27,045	34
36	8,425	11,788	15,728	19,581	23,940	28,508	36
38	8,890	12,438	16,614	20,658	25,251	29,971	38
40	9,355	13,088	17,500	21,735	26,562	31,434	40
Velocity	222	246	274	288	306	324	in Feet

FALL 10 FEET PER MILE.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f.0in.	1 f.3in.	1 f.6 in.	1 f.9in.	2 f.0in.	2 f.3in.	Feet.
2	582	858	1,187	1,570	2,017	2,515	2
4	1,062	1,526	2,058	2,661	3,341	4,088	4
6	1,542	2,194	2,929	3,752	4,665	5,661	6
8	2,022	2,862	3,800	4,843	5,989	7,234	8
10	2,504	3,529	4,671	5,935	7,314	8,806	10
12	2,994	4,198	5,567	7,060	8,686	10,399	12
14	3,484	4,867	6,463	8,185	10,058	11,992	14
16	3,974	5,536	7,359	9,310	11,430	13,585	16
18	4,465	6,205	8,255	10,435	12,802	15,178	18
20	4,956	6,942	9,150	11,563	14,175	16,971	20
22	5,447	7,612	10,051	12,698	15,554	18,618	22
24	5,938	8,282	10,952	13,833	16,933	20,265	24
26	6,429	8,952	11,853	14,968	18,312	21,912	26
28	6,920	9,622	12,754	16,103	19,691	23,559	28
30	7,410	10,370	13,654	17,237	21,074	25,207	30
32	7,901	11,040	14,555	18,372	22,451	26,854	32
34	8,392	11,710	15,456	19,507	23,830	28,501	34
36	8,883	12,380	16,357	20,642	25,209	30,148	36
38	9,374	13,050	17,258	21,777	26,588	31,795	38
40	9,865	13,720	18,159	22,912	27,967	33,442	40
Velocity	236	252	284	304	322	339	in Feet

per Minute, Fall 9 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2f. 6in.	2f. 9in.	3f. 0in.	3f. 3. in.	3f. 6 in.	3f. 9. in.	Feet.
2	2,922	3,522	4,185	4,911	5,712	6,579	2
4	4,659	5,514	6,444	7,446	8,529	9,693	4
6	6,396	7,506	8,703	9,981	11,346	12,807	6
8	8,133	9,498	10,962	12,516	14,163	15,921	8
10	9,867	11,490	13,218	15,051	16,989	19,032	10
12	11,676	13,572	15,585	17,727	19,956	22,314	12
14	13,485	15,654	17,952	20,403	22,923	25,596	14
16	15,294	17,736	20,210	23,079	25,890	28,878	16
18	17,103	19,818	22,686	25,755	28,857	32,160	18
20	18,921	21,909	25,059	28,431	31,833	35,451	20
22	20,748	24,015	27,456	31,119	34,845	38,787	22
24	22,575	26,121	29,853	33,807	37,857	42,123	24
26	24,402	28,227	32,250	36,495	40,869	45,459	26
28	26,229	30,333	34,647	39,183	43,881	48,795	28
30	28,068	32,448	37,050	41,871	46,902	52,137	30
32	29,895	34,554	39,450	44,586	49,914	55,473	32
34	31,722	36,660	41,868	47,301	52,926	58,809	34
36	33,552	38,766	44,277	50,016	55,938	62,145	36
38	35,382	40,872	66,686	52,731	58,940	65,481	38
40	37,212	42,978	69,095	55,446	61,952	68,817	40
per	339	351	363	375	390	399	Minute.

Fall 10 Feet per Mile.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2 f. 6 in.	2 f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	3,082	3,716	4,415	5,181	6,026	6,931	2
4	4,913	5,817	6,796	7,851	8,994	10,215	4
6	6,744	7,918	9,177	10,521	11,962	13,499	6
8	8,575	10,019	11,558	13,191	14,930	16,783	8
10	10,408	12,120	13,940	15,863	17,900	20,065	10
12	12,319	14,311	16,436	18,685	21,032	23,526	12
14	14,230	16,502	18,932	21,507	24,164	26,987	14
16	16,141	18,693	21,428	24,329	27,296	30,448	16
18	18,052	20,884	23,924	27,151	30,428	33,909	18
20	19,962	23,079	26,422	29,973	33,559	37,373	20
22	21,887	25,304	28,949	32,807	36,736	40,891	22
24	23,812	27,529	31,476	35,641	39,913	44,409	24
26	25,737	29,754	34,003	38,475	43,090	47,927	26
28	27,662	31,979	36,530	41,309	46,267	51,445	28
30	29,591	34,207	39,060	44,142	49,445	54,965	30
32	31,516	36,432	41,587	46,976	52,622	58,483	32
34	33,441	38,657	44,114	49,810	55,799	62,001	34
26	35,366	40,882	46,641	52,644	58,976	65,519	36
38	35,391	43,107	49,168	55,478	62,153	66,037	38
40	37,216	45,332	51,695	58,312	65,330	69,555	40
per	355	369	383	397	409	425	Minute.

AUXILIARY TABLE III.—SHOWING THE DISCHARGE IN

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	1 f. 0 in.	1 f. 3 in.	1 f. 6. in.	1 f. 9 in.	2 f. 0 in.	2 f. 3 in.	Feet.
2	184	271	375	496	637	795	2
3	260	376	512	668	846	1,043	3
4	336	482	650	841	1,055	1,292	4
5	412	587	787	1,013	1,264	1,540	5
6	488	693	925	1,186	1,473	1,789	6
7	564	798	1,062	1,358	1,682	2,037	7
8	640	904	1,200	1,531	1,891	2,286	8
9	716	1,009	1,333	1,703	2,100	2,534	9
10	792	1,116	1,477	1,875	2,311	2,782	10
11	870	1,221	1,618	2,053	2,528	3,040	11
12	949	1,332	1,760	2,231	2,745	3,299	12
13	1,027	1,440	1,901	2,409	2,962	3,557	13
14	1,102	1,548	2,043	2,587	3,179	3,816	14
15	1,180	1,656	2,184	2,765	3,396	4,174	15
16	1,257	1,764	2,326	2,943	3,613	4,333	16
17	1,335	1,872	2,467	3,121	3,830	4,591	17
18	1,412	1,980	2,609	3,299	4,047	4,850	18
19	1,490	2,088	2,750	3,477	4,264	5,108	19
20	1,567	2,195	2,893	3,656	4,482	5,366	20
Velocity	74	82	90	96	102	108	in Feet,

AUXILIARY TABLE III.—*continued.*

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	4 f. 0 in.	4 f. 3 in.	4 f. 6 in.	4 f. 9 in.	5 f. 0 in.	5 f. 3 in.	Feet.
2	2,514	2,844	3,200	3,553	3,969	4,471	2
3	3,033	3,465	3,889	4,286	4,739	5,312	3
4	3,603	4,086	4,572	5,020	5,509	6,153	4
5	4,174	4,707	5,255	5,753	6,300	9,994	5
6	4,744	5,328	5,940	6,487	7,091	7,835	6
7	5,316	5,949	6,623	7,220	7,882	8,676	7
8	5,888	6,570	7,308	7,954	8,672	9,517	8
9	6,496	7,191	8,012	8,687	9,512	10,358	9
10	7,104	7,812	8,716	9,423	10,352	11,198	10
11	7,712	8,469	9,420	10,195	11,192	12,087	11
12	8,320	9,126	10,120	10,968	12,032	12,976	12
13	8,928	9,783	10,822	11,740	12,880	13,865	13
14	9,534	10,440	11,504	12,513	13,728	14,754	14
15	10,142	11,097	12,206	13,285	14,576	15,644	15
16	10,752	11,754	12,908	14,058	15,424	16,533	16
17	11,360	12,411	13,610	14,830	16,264	17,422	17
18	11,968	13,068	14,312	15,603	17,104	18,311	18
19	12,574	13,725	15,014	16,375	17,944	19,200	19
20	13,184	14,382	15,737	17,147	18,784	20,091	20
Velocity	138	140	143	146	150	152	in Feet,

CUBIC FEET PER MINUTE, FALL 1 FOOT PER MILE.

Breadth of bottom.	Depth of Water, in Feet and Inches.						Breadth of bottom.
Feet.	2f. 6 in.	2f. 9 in.	3 f. 0 in.	3 f. 3 in.	3 f. 6 in.	3 f. 9 in.	Feet.
2	974	1,174	1,395	1,637	1,904	2,193	2
3	1,263	1,506	1,771	2,059	2,371	2,713	3
4	1,553	1,838	2,148	2,482	2,843	3,233	4
5	1,842	2,170	2,524	2,904	3,312	3,753	5
6	2,132	2,503	2,901	3,327	3,782	4,269	6
7	2,421	2,834	3,277	3,749	4,251	4,789	7
8	2,711	3,166	3,654	4,172	4,721	5,307	8
9	3,000	3,498	4,030	4,594	5,190	5,827	9
10	3,289	3,830	4,406	5,017	5,663	6,344	10
11	3,692	4,177	4,800	5,463	6,132	6,891	11
12	3,892	4,524	5,195	5,909	6,652	7,438	12
13	4,194	4,871	5,589	6,355	7,146	7,985	13
14	4,495	5,218	5,984	6,801	7,641	8,532	14
15	4,796	5,565	6,378	7,247	8,135	9,079	15
16	5,098	5,912	6,773	7,693	8,630	9,629	16
17	5,399	6,259	7,167	8,139	8,124	10,173	17
18	5,701	6,606	7,562	8,585	9,619	10,720	18
19	6,002	6,953	7,956	9,031	10,113	11,267	19
20	6,307	7,303	8,353	9,477	10,611	11,817	20
Velocity	113	117	121	125	130	133	in Feet.

AUXILIARY TABLE IV.—OF MULTIPLIERS AND DIVISORS.

Feet fall per mile.	Once.	Twice.	Quadruple.	Feet fall per mile.	Once.	Twice.	Quadruple.
1.0	1.000	5.657	32.000	13	3.605	20.400	115.360
1.6	1.225	6.928	39.200	14	3.742	21.166	119.744
2.0	1.414	8.000	45.248	15	3.873	21.909	123.936
2.6	1.581	8.944	50.592	16	4.000	22.627	128.000
3.0	1.732	9.796	55.424	17	4.123	23.323	131.936
3.6	1.871	10.580	59.872	18	4.242	24.000	135.744
4.0	2.000	11.312	64.000	19	4.359	24.656	139.488
4.6	2.121	12.000	67.872	20	4.472	25.298	143.104
5.0	2.236	12.648	71.552	21	4.583	25.923	146.656
5.6	2.345	13.264	75.040	22	4.690	26.533	150.080
6.0	2.449	13.856	78.368	23	4.796	27.129	153.472
6.6	2.569	14.420	82.208	24	4.899	27.713	156.763
7.0	2.645	14.968	84.640	25	5.000	28.284	160.000
7.6	2.757	15.492	88.224	26	5.100	28.844	163.200
8.0	2.828	16.000	90.496	27	5.196	29.393	166.272
8.6	2.933	16.492	93.856	28	5.292	29.933	169.344
9.0	3.000	16.948	96.000	30	5.477	30.984	175.264
9.6	3.098	17.416	99.152	32	5.656	32.000	180.992
10.0	3.162	17.888	101.184	36	6.000	33.896	192.000
11.0	3.316	18.761	106.112	38	6.196	34.832	198.304
12.0	3.464	19.596	110.848	40	6.324	35.776	202.368

TABLE V.—SHOWING THE DISCHARGE, OVER WEIRS,

Depth of Water, in Feet.	Length of WEIR, in Feet.					Depth of Water, in Feet.
	1	2	3	4	5	
0.10	6.74	13.49	20.24	26.99	33.74	0.10
0.20	19.10	38.21	57.31	76.42	95.52	0.20
0.30	35.11	70.23	105.34	140.46	175.57	0.30
0.40	53.99	107.99	161.99	215.99	269.98	0.40
0.50	75.51	151.03	226.55	302.07	377.59	0.50
0.60	99.27	198.54	297.82	397.09	496.37	0.60
0.70	125.10	250.21	375.31	500.42	625.53	0.70
0.80	152.84	305.68	458.52	611.36	764.20	0.80
0.90	183.37	366.75	550.12	733.50	916.88	0.90
1.00	213.60	427.20	640.80	854.40	1068.00	1.00
1.10	245.50	491.00	736.50	982.01	1227.51	1.10
1.20	280.67	561.34	842.01	1122.68	1403.35	1.20
1.30	316.59	633.18	949.77	1266.36	1582.96	1.30
1.40	353.83	707.66	1061.49	1415.33	1769.16	1.40
1.50	392.43	784.86	1177.29	1569.72	1962.15	1.50
1.60	431.98	863.96	1295.94	1727.92	2159.90	1.60
1.70	473.45	946.91	1420.36	1893.82	2367.28	1.70
1.80	517.25	1034.50	1551.75	2069.01	2586.26	1.80
1.90	559.41	1118.82	1678.23	2237.64	2797.06	1.90
2.00	604.09	1208.18	1812.27	2416.36	3020.46	2.00
2.10	650.02	1300.05	1950.07	2600.10	3250.13	2.10
2.20	697.04	1394.08	2091.12	2788.16	3485.20	2.20
2.30	744.97	1489.94	2234.91	2979.88	3744.85	2.30
2.40	794.19	1588.38	2382.57	3176.76	3970.96	2.40
2.50	844.33	1688.66	2532.99	3377.32	4221.65	2.50
2.60	895.46	1790.93	2686.39	3581.86	4477.33	2.60
2.70	947.65	1895.30	2842.95	3790.60	4738.25	2.70
2.80	1000.84	2001.69	3002.54	4003.39	5004.24	2.80
2.90	1054.87	2109.74	3164.61	4219.48	5274.35	2.90
3.00	1109.90	2219.80	3329.70	4439.60	5549.50	3.00
3·25	1251.50	2503.00	3754.50	5006.00	6257.50	3.25
3.50	1398.64	2797.28	4195.92	5594.56	6993.20	3.50
3.75	1551.30	3102.60	4653.70	6205.20	7756.50	3.75
4.00	1708.80	3417.60	5126.40	6835.20	8544.00	4.00
4.25	1871.50	3743.00	5614.50	7486.00	9357.50	4.25
4.50	2039.00	4078.00	6117.00	8156.00	10195.00	4.50
4.75	2211.30	4422.60	6633.90	8845.20	11056.50	4.75
5.00	2388.15	4776.30	7164.46	9552.61	11940.77	5.00

PER MINUTE, IN CUBIC FEET.

Depth of Water, in Feet.	Length of Weir, in Feet.					Depth of Water, in Feet.
	6	7	8	9	10	
0.10	40.49	47.24	53.99	60.74	67.49	0.10
0.20	114.63	133.73	152.84	171.94	191.05	0.20
0.30	210.69	245.81	280.92	316.04	351.15	0.30
0.40	323.98	377.98	431.98	485.97	539.97	0.40
0.50	453.11	528.63	604.15	679.67	755.19	0.50
0.60	595.64	694.91	794.19	893.46	992.74	0.60
0.70	750.63	875.74	1000.84	1125.95	1251.06	0.70
0.80	917.04	1069.89	1222.73	1375.57	1528.41	0.80
0.90	1100.25	1283.63	1467.00	1650.38	1833.76	0.90
1.00	1281.60	1495.20	1708.80	1922.40	2136.00	1.00
1.10	1473.01	1718.52	1964.02	2209.52	2455.03	1.10
1.20	1684.02	1964.69	2245.36	2526.03	2806.70	1.20
1.30	1899.55	2216.14	2532.73	2859.32	3165.92	1.30
1.40	2122.99	2476.83	2830.66	3184.49	3538.33	1.40
1.50	2354.58	2747.01	3139.44	3531.87	3924.30	1.50
1.60	2591.88	3023.86	3455.84	3887.82	4319.80	1.60
1.70	2840.73	3314.19	3787.64	4261.10	4734.56	1.70
1.80	3103.51	3620.77	4138.02	4655.27	5172.53	1.80
1.90	3356.47	3915.88	4475.29	5034.70	5594.12	1.90
2.00	3624.55	4228.64	4832.73	5436.82	6040.92	2.00
2.10	3900.15	4550.18	5200.20	5850.23	6500.26	2.10
2.20	4182.24	4879.28	5576.32	6273.36	6970.40	2.20
2.30	4469.82	5214.79	5959.76	6704.73	7449.70	2.30
2.40	4765.15	5559.34	6353.53	7147.72	7941.92	2.40
2.50	5065.98	5910.31	6754.64	7598.97	8443.33	2.50
2.60	5372.80	6268.26	7063.72	8059.19	8954.66	2.60
2.70	5685.90	6633.55	7581.20	8528.85	9476.50	2.70
2.80	6005.08	7005.93	8006.78	9007.63	10008.48	2.80
2.90	6329.22	7384.09	8438.96	9493.83	10548.70	2.90
3.00	6659.40	7769.30	8879.20	9989.10	11099.00	3.00
3·25	7509.00	8760.50	10012.00	11263.50	12515.00	3.25
3.50	8391.84	9790.48	11189.12	12587.76	13986.40	3.50
3.75	9307.80	10859.10	12410.40	13961.70	15513.00	3.75
4.00	10252.80	11961.60	13670.40	15379.20	17088.00	4.00
4.25	11229.00	13100.50	14972.00	16843.50	18715.00	4.25
4.50	12234.00	14273.00	16312.00	18351.00	20390.00	4.50
4.75	13267.80	15479.10	17690.40	19901.70	22113.00	4.75
5.00	14328.92	16717.07	19005.23	21493.38	23881.54	5.00

SECTION XII.

ON THE DISCHARGE OF WATER THROUGH SLUICES.

A SLUICE is a frame of timber, stone, iron, or other material serving to retain and rise the water of a River, Canal, &c., and also permit it to pass occasionally; as the sluice of a Mill, which stops and collects the waters of a stream that it may subsequently be let fall in greater abundance on the Mill-wheel.

Other sluices are used as vents or drains to discharge the water from the land, and for the protection of low lands from being inundated by the waters of the sea.

The Gate or Valve of a sluice is generally made to move by machinery in a vertical position, so as to admit the water to pass through any required sectional area; if the gates or valves are suspended by hinges they are generally termed *self-acting* sluices.

When water issues through an aperture, as in a sluice, the lateral particles press obliquely from all directions to the orifice, which causes the issuing water to converge towards the axis of the jet, and this contraction takes place in all cases where fluids are made to pass through narrow or confined places, as in Pipes, Canals, Sluices, Weirs, Dams, &c., and was denominated by the famous Sir Isaac Newton the *vena contracta*, or contracted vein—*vide* prop. 26, book II, of his *Mathematical Principles*, by Motte.

Fig. No. 12 is an attempt to represent the motion of water in these different situations; thus, *a* exhibits the motion through a thin plate, *b* the motion through a *tube* of two diameters of the orifice in length, *c* when the tube projects inwardly, in which case it is difficult to make it flow full, *d* is the representation of a *mouth-piece*, generally termed a *bell-mouth*, formed to the shape which the jet would *naturally* assume ; in this case all the contraction is avoided, and the orifice may be taken at its full dimensions as nothing now interferes to diminish the discharge, if we except a very small friction of the sides. Michelotte felt considerable interest in the investigation of the nature of this *mouth-piece ;* after carefully observing the *form* and dimensions of a natural jet, he succeeded in making one which gave a discharge of 983, when the natural discharge would have been 1000, which shews the utility of applying it when an efficient discharge is requisite. It is formed by the revolution of a *cycloid* or *trochoid*, which is a mechanical curve of singular and curious properties, for the *cycloidal space* contained between the curve and the base is triple the generating circle, while the length of the whole curve of the cycloid is four times the diameter of the same generating circle. Figs. 13 and 15 represent the motion of water over a *dam* or *weir* when the fall is free and undisturbed, the surface of the lower stream being under the edge or sole of the *waste-board ;* Fig. 14 shews the motion of water over a bar or keep, such as had been calculated for the *new cut* mentioned in page 53, leading from *m* to P.—*Vide* Fig. 1.

It will simplify and abridge calculations in this department, by considering the discharge under these different circumstances, as moving with a common or *mean* velocity, which may be conceived as generated or produced by a fall accommodated to the discharge: and also to know the height or depth of water that would produce the velocity with which it issues in these situations, and this height is, what is technically termed the *Head of water.*

That the discharge may agree with the results found by observation, it should be calculated on the supposition that the orifice is diminished to the dimensions of the smallest section of the contraction, or the discharge may be computed from the *real* dimensions of the orifice, and then corrected by means of actual comparison with the computed real discharges, made in a series of experiments in situations similar to those which most frequently occur in practice. The amount of this contraction, according to *Bossut*, is about one-third, which reduces the diameter to 0.666 of the orifice ; *Venturi* makes it 0.631, and *Etelwein* 0.64. The table of sluices has been calculated on the supposition of the orifice being contracted to 0.625, or to five-eighth of its diameter.

The natural velocity of the water issuing from an orifice is that which a heavy body would acquire in falling from the horizontal surface of the water, and is shewn in Table No. 8 for every head of water from 3 inches to 15 feet, while the real or effective velocity is given in the 3rd column, and the discharge per minute, from a sectional area of *one* square foot, is shown in the 4th column.

TO FIND THE NATURAL AND EFFECTIVE VELOCITIES FOR ANY GIVEN HEAD OF WATER PASSING THROUGH A SLUICE.

Rule.—*Multiply the square root of the height by eight for the natural, and by five for the effective velocity, and the product will be the velocities required.*

Example—What are the natural and effective velocities for 9 feet head of water?

$$\sqrt{9} = 3 \times 8 = 24 \text{ the natural velocity}$$
$$\sqrt{9} = 3 \times 5 = 15 \text{ the effective velocity}$$

per second, as may be seen by inspection of the table for finding the discharge through sluices.

To find the Head of water that will produce a given natural velocity—

Rule.—*Divide the given velocity by* 8 *and the square of the quotient will be the Head of water required; and in general terms will run thus:—*

$$8\sqrt{h} = v \quad \because \quad h = \left(\frac{v}{8}\right)^2$$

Example.—What must be the Head of water to produce a natural velocity of 24 feet per second?

$$\frac{24}{8} = 3 \ \& \ 3^2 = 9$$

the Head or depth of water required.

APPLICATION OF TABLE NO. 8 OF SLUICES.

Look for the given head* of water in the margin, and under head of discharge per minute, will be found the number of cubic feet discharged per minute due to this head of water, and *one* square foot of sectional area, which multiplied by the given sectional area of the sluice and the product will be the discharge per minute in cubic feet.

Example.—What would be the discharge per minute from a Sluice 4 feet wide and 15 inches deep having a head of 10 feet of water?

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* The head of water is generally calculated as the height from the centre of the orifice to the surface of the water.

The Tabular number opposite 10 feet head of water is 948.66
which multiplied by the sectional area = 4 × 1.3 = 5

gives the discharge per minute in cubic feet = 4743.3

What will be the discharge per minnte through a circular orifice, one foot diameter, with 9 feet head of water?

The velocity of 9 feet head of water is, per table—
15 feet per second, or 900 per minute
multiply by .7854 the sectional area

the discharge 7068.600 cubic feet per minute,
and so proceed to find the discharge for any other orifice, by multiplying the velocity due to the head of water as already shown, by the sectional area, and it will give the discharge, let the figure be of any shape or dimensions whatever.

SECTION XIII.

OF DE BUÂT'S UNIVERSAL FORMULA FOR PIPES, CANALS, WATER-COURSES, ETC.

This formula of De Buât's, which had been noticed in the beginning of this work, runs as follow :—

$$\frac{307\sqrt{d-0{\cdot}1}}{\sqrt{s}-L\sqrt{s+1{\cdot}6}}-0{\cdot}3\sqrt{d-0{\cdot}1}=\text{vel. per sec.}$$

It consists of 3 parts, the first $307\sqrt{d-0{\cdot}1}$ the numerator of the fraction, a *function* of the hydraulic mean depth, and is represented in Table 6 under the denomination of Log. A. The second is the denominator $\sqrt{s}-L\sqrt{s+1{\cdot}6}$ represents the *ratio* of *slope* or *inclination* of the conduit, and represented in Table No. 7 by Log. B. The third part $-0{\cdot}3\sqrt{d-0{\cdot}1}$ is also a function of the hydraulic mean depth representing the viscidity of water, and is shown in Table No. 6, under that head, and corresponding to the several hydraulic mean depths in the margin. By the help of these three parts, which De Buât, with incredible assiduity and skill, so proportioned and arranged as to enable us to calculate the *velocity* of any stream or conduit to a degree of accuracy far beyond our most sanguine expectations.

The following Table, the results of various experiments, made by him, Abbe Bossut, and Mr. Couplet, will exhibit the wonderful accuracy of this *formula*, whether applied to Pipes, Rivers, Canals, or Aqueducts.

Experiments made by	Velocity per second by experimt.	Calculated Theoretic velocity.	Experiments made by	Velocity per second by experimt.	Calculated Theoretic velocity.
	Inches.	Inches.		Inches.	Inches.
De Buât on	11.704	12.006	Mr. Couplett's	58.903	58.803
vertical pipes,	9.753	10.576	gave,	5.323	5.278
tubes, of small	45.648	46.210	With a tube,	4.127	4.225
diameters.	41.614	41.714		3.154	3.338
	51.150	50.938	In a wooden	39.159	40.510
In horizontal	33.378	33.167	trapezoidal	27.510	27.190
position.	10.630	10.492	canal,	28.920	29.880
The Abbe	22.282	21.975		31.890	31.320
Bossut's gave	12.923	11.756		32.520	31.610
	18.943	18.749		30.160	30.600
In a rectangu-	20.240	18.660	On the river	35.110	27.620
lar canal,	28.290	26.690	Haine,	31.770	28.760
	13.560	12.530		13.610	12.080
	12.100	11.760		15.969	13.530
	15.550	15.240		16.140	15.220

These comparisons of the velocities observed in the actual experiments, with the calculations of the same, will be acknowledged most satisfactory, and must add considerable weight to the validity of the principles laid down by him, in his *analysis* of the mechanism of uniform hydraulic motion, and also afford the ENGINEER great confidence in a *theory* so fairly established. It must be also highly creditable to the genius of De Buât, although he candidly informs us that to Benezech De St. Honore, a young officer of Engineers, is due the credit of finding out the precise form of expression in this analytical formula.

We shall now proceed to apply it to the solution of those questions of *practical* utility, which are of frequent use in the several departments of Hydraulic Engineering.

TO FIND WHAT QUANTITY OF WATER WOULD A CONDUIT OF ANY GIVEN DIMENSION CONVEY, WITH A GIVEN RATE OF INCLINATION.

GENERAL RULE.—*Find the hydraulic mean depth of the given conduit, as explained in sec. 6, p. 33, and sec. 7, p. 40, then under the head of Hydraulic Mean Depth of Conduit, in Table No. 6, find Log. A, and the corresponding viscidity C, which note down: again, in Table 7, corresponding to the given rate of inclination, will be found Logarithm B, which, taken from log. A, the remainder will be the log. of the velocity, plus the vicidity from the natural number corresponding to this log.; take the number denoting the vicidity, and the remainder will be the velocity per minute; and, lastly, multiply this velocity by the sectional area in square feet, and the product will be the discharge in cubic feet per minute.*

EXAMPLE No. 1.—What quantity of water would a Pipe of six inches diameter yield on an incline plane of 1 in 800?

In Table 6, corresponding to 6 inches,* or 1½ inches, the hydraulic mean depth, will be found—

---

* When the discharge through a Pipe is required, the diameter will be found in the marginal column of Table No. 6, and the corresponding hydra. mean depth opposite, so that in *this* case there is no necessity to calculate the hydraulic mean.

Log. A = 3.23715 and viscidity C. = 1.70
Log. B = 1.39690 in Table 7;
Diff. = 1.84025 = Nat. number = 69.22
Velocity = 67.52 per minute.
$\frac{6^2 \times .7854}{144}$ = area of pipe = .1963 square feet.
Discharge 12.25 C. Ft. per min.

What would the same Pipe convey if the ratio of inclination was 1 in 100?

Log. A. = 3.23715 Vis. 1.70
Log. B. = 0.88593
Nat. No. for 2.35122 = 224.50
Velocity = 222.8 per minute.
Sectional area = $6^2 \times .7854$ = 28.72
144) 6298.556
The discharge in cubic feet 43.74 per min.

The Hydraulic Mean for a circle being half the radius, as already noticed in page 40, we have, when D is the diameter, and *d* the hydraulic mean,

$$D^2 = 16\,d^2 \text{ and } \frac{D^2}{2} \times .7854 = 8\,d^2 \times .7854 = d^2\,6.2832,$$

which, divided by 144, gives .04363 d^2, and, multiplied by the velocity, will give the discharge for a pipe running *half* full, hence the following Rule:—

To the const. Log. of .04363
Add the Log. of A,
And deduct the Log. B, and the natural number corresponding to this log. of the remainder, multiplied by the square of the hydraulic mean, in inches, will give the discharge, in cubic feet, per minute.

Example.—What will be the discharge through a circular pipe, 12 inches diameter, running half fall, with an inclination of 1 in 100?

Constant Log. of .04363 = –2.63978
$\frac{12}{4}$ = 3 the Hyd. Mean, Log. of A, 3.39886 Viscidity 2.45
2.03864
Deduct Log. B for inclination, 0.88593
1.15271 Nat. No. = 14.22
Hydraulic Mean 3^2 = 9
Discharge 127.98

Or the work may be simplified by the following form:—

Log. A, for the Hyd. Mean D. = 3.39886 Vis. 2.45
Log. B, for rate of inclin. 1 in 100 = 0.88593
2.51293 = 325.80

Velocity in feet, per minute, 323.35
Multiplied by the sectional area .7854

Cubic feet per minute, 127.0000 as before.

In this manner the discharge for any pipe may be ascertained, and is the way in which Table No. 10 was computed; which, although calculated for only half the discharge, by doubling the numbers found in the Table, we have the entire discharge. By it we can also find, by inspection, what will be the dimensions of a pipe which will give double, treble, or any other multiple of the discharge of another pipe,—thus, the discharge of a 12-inch pipe, with an inclination of 1 in 100, will be six times that of a 6-inch pipe, with the same rate of inclination. It will be of great importance to know that it requires a certain *length* of pipe to put it in *train*, which cannot well be determined by theory ; but it is well known that pipes of greater diameter will require a greater length, and this in proportion to the square of the diameter. Our favourite author found it to agree well with his experiments, for a pipe of one inch diameter sustained no change of velocity by gradually shortening it till he had reduced it to six feet, and then it discharged a little more water; and a pipe of two inches diameter gave a sensible augmentation of velocity when shortened to 25 feet. From hence, and his other experiments, he deduced the following useful result, viz., that the square of the diameter in inches multiplied by 72 will express the length, in inches, necessary for putting any pipe in train.—*Vide Encyclopædia Britannica*, article WATERWORKS.

This TABLE may be applied with great advantage to cases where CITIES, TOWNS, DISTILLERIES, BREWERIES, or any other description of Factories are to be supplied with pipe water, and it will also serve as a guide to persons engaged in the drainage of land, as it will enable them to make their MAIN, *sub-main*, and parallel drains of suitable dimensions ; which may be, without disparagement to any, said that *very* few have been heretofore able to determine with precision. But it should not be considered singular, as the investigation of those subjects is very intricate and laborious. This Table, it is presumed, will give satisfactory results, when combined with Table No 1, of Catchment Basins.

For example, what should be the diameter of a Pipe or Tube half full, capable of conveying the waters off 5 acres in times of floods, if the inclination be 1 in 70 feet?

By inspection of Table No. 1, of Catchment Basins, under the head of PIPES and TILES,* opposite 5 acres will be found 12.5 cubic feet, the discharge per minute

---

*** That portion of Table No. 1 for Pipes and Tiles is calculated on the hypothesis that the water finds its way into those pipes or tiles in *half* the time it takes to pass into the rivers, but should any person engaged in the drainage of land be of a different opinion, let him calculate the discharge as shown in pages 24 and 25, and then enter the table for discharge of pipes, and he will find the diameter as already shown.**

from this quantity of land; again, look to Table 10, opposite to 70, the given rate of inclination for 12.5, and opposite 4.4 inches will be found 11.99; therefore 4.4 inch, or say 4½ inches, will be the dimensions of pipe required.

To show the further application of the Table of Pipes, take the following

Example.—A. B., a wealthy Brewer, was supplied by a certain Corporation with pipe water by two pipes, one 6 inches in diameter and the other 9 inches diameter; and finding his supply insufficient, applied to the *Board* for permission to lay down one *new* pipe in place of the two old ones, whose diameter was to be 12 inches. *Quere*—What loss, if any, did the Brewer sustain, supposing the rate of inclination of the pipes to be 1 feet in 80?

By inspection, 6 inches diameter, gives	24.3	cubic feet,
And 9 inches diameter gives	68.4	„
Both give, per minute,	92.7	cubic feet,
And 12-inch diameter gives	141.0	„
Difference, in cubic feet,	48.3	per minute.

So that the worthy Brewer seemed to know something of *Hydraulics*, as he gained 2 × 48.3 = 96.6 cubic feet per minute, by his ingenuity.

Required the dimensions of a pipe that will convey 623.21 gallons per minute to a Town or Factory, where the fall is 1 in 80.

By Table 9th, for changing cubic feet into Hhds. and Gallons, and the contrary, we find that this quantity of water is equal to 100 cubic feet; take half this sum, viz., 50 (for the pipes are calculated only to run *half* full) and in the column for rate of inclination 80, and corresponding to 8 inches in the margin, will be found 50.6 cubic feet, therefore 8 inches is the diameter required.

Example No. 2.—Required the velocity per minute, and discharge due to a River 20 feet bottom, 3 feet deep, side slopes 1 to 1 and 8 feet fall per mile, or 1 in 660. *Vide* example No. 2, page 35, where

The sectional area = 69; the border 28.48, and the hydraulic mean depth 2.42 feet.

Log. A. of hydr. mean 2.42 = 3.90000 and viscidity C. = 7.9
Log. B. for inclin. 1 in 660 = 1.35108

Log. 2.54892 Natural No. = 353.9

Vel. per min. in feet 346
Sectional area = 69

The discharge per minute in cubic feet 23,874
Ditto, per Table 2, for 8 feet fall 23,626

Difference 248

which shows the correctness of each, although calculated from *different* and *independent data.*

EXAMPLE No. 3.—Suppose the depth of water in a CANAL to be 8 feet, and bottom 40 feet, the fall per mile 4 feet, required the discharge per minute.

Here the border is 62.62 and the sectional area 384, which gives the hydraulic mean 6.14 feet.

Log. A for hydra. mean 6.14 feet = 4.11480 Vis. 12.75
Log. B for incline 1 in 1320 = 1.51493

2.59983 = 397.96

385.21
Multiplied by the sectional area = 384

The discharge in c. ft. per min. 147.910
Do. by Table No. 2, 147,900

Difference per minute, 10

A greater proof could not be expected.

EXPLANATION AND USE OF TABLES NOS. 9, 10, 11, 12, 13 AND 14.

A Town is to be supplied with 2144 Gallons of Water per minute, from a reservoir elevated 53 feet above the place of delivery, which is just one mile from the Reservoir, what will be the diameter of a Pipe capable of conveying it thence?

By inspection of Table No. 9, it will be seen that

1869.60 gallons = 300 cubic feet,
249.28 „ = 40 „
24.92 „ = 4 „

and ∵ 2143.80 gallons = 344 cubic feet.

And by inspection in Table No 13, it will be found that a fall of 53 feet per mile gives a *rate* of *inclination* of 1 in 99.6, say 1 in 100. Now look for *that rate* of inclination in Table No. 10, for Pipes, and for 344 cubic feet, the discharge *under it*, and corresponding to 18 inches diameter will be found the discharge; therefore, that will be the dimension of pipe required.

Again, required the dimensions of a Water-course capable of supplying a Mill with 5609 gallons per minute, and what will be its mean velocity, when the fall is two feet per mile?

By inspection in Table 9, it will be seen that 5609 gallons are equal to 900 cubic feet. Now enter Table No. 2 under fall 2 feet per mile, and corresponding to 2 feet bottom and 2 feet deep, will be found the discharge required; and by further inspection under the depth and corresponding to the velocity, will be found 144 feet, the mean velocity per minute, which is, according to Table No. 12, 1.637 miles per hour, and the effect this velocity will have on the bottom of the watercourse may be known at page 32.

Table the 11th, of Hydraulic Equivalents, will be found very useful, as by it we can contract or expand a *River* or *Watercourse*, still retaining the same discharge. The following example will elucidate it. Suppose a River 30 feet bottom and 2 feet deep, is to be conveyed by a new cut to a Mill, having the same rate of inclination as the River, what would be the several depths and corresponding breadth of bottom required to effect the intention?

Look in the Table for 2 feet the depth, at the top, under *depth of water in feet and inches*, and for the given breadth of bottom, in the vertical column, and in a horizontal line to the left will be found

23 16 13 10 7 6 4 3 the botttoms, and
2.6 3.0 3.6 4.0 4.6 5.0 5.6 6.0 the corresponding

depths at top, each of which will answer.

For more particular information on this useful point, see *Auxiliary* Table No. 3, where equivalents to any dimensions may be readily found. By help of this Table, we can so extend the bottom of the *tail-race* of a mill so as to prevent, to a certain extent, the effects of *back-water*.

Table No. 14 will be found of considerable use, and its construction has been given in page 30. Suppose the *Super-*

ficial[*] Velocity of a River to be 125 feet per minute, what will be its *Mean* Velocity and Discharge, supposing its sectional area to be 20 square feet? By inspection of the Table it will be found that a Superficial Velocity of 125 feet will give a *Mean* Velocity of 102.5 feet per minute, which, multiplied by 20, the sectional area, will give 2050, the discharge per minute for this River.

Again, by inspection of the *mean* velocities in Table No. 2, you will find, corresponding to 2 feet deep and 1 foot fall per mile, 102 feet, which is the nearest velocity to 102.5; and by examining the same column of discharges, for the calculated discharge 2050, we find 2311 the nearest, hence it may be inferred that this River is 10 feet broad, 2 feet deep, and had a fall of 1 foot per mile, and likewise a velocity at bottom of 80 feet per minute. According to the observations in page 32, this velocity would carry off coarse gravel, and the amount of its discharge per minute in gallons, will be according to Table No. 9, as follows:—

2000 cubic feet = 12464 gallons
50 „ = 311 „

∵ 2050 cubic feet = 12775 gallons,

Which, at 10 lbs. avoirdupoise per gallon, would weigh 57 tons.

Having observed the *Superficial* Velocity of a Mill-race to be 355 feet per minute, I measured its dimensions, which were found to be 4 feet wide and 2 feet deep. *Quere*—The Mean Velocity, the discharge in cubic feet and imperial gallons, likewise the depth the water will run in the tail-race, if the breadth thereof be 10 feet, with an inclination of 5 feet per mile?

By inspection in Table No. 14 of Superficial Velocities, the *Mean* Velocity, will be found to be 315 feet per minute, which, multiplied by 8, the Sectional area, gives 2520 cubic feet, the discharge per minute, which will be 15705 gallons, by Table 9th, and corresponding to 10 feet bottom, in Table No. 2, and the given discharge will be found 1 foot 3 inches, the depth the water will run at in the tail-race, which is 9 inches lower than in the head-race.

We shall conclude this section by observing, that the circumstances connected with each case which may occur, will suggest many other applications of these Tables.

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[*] The Superficial Velocity can easily be found by observation.

Table VI.—For Finding the Velocity and Discharge, per Minute, of Rivers, Canals, Aqueducts, Pipes, &c., calculated from De Buat's Formula,

$$\frac{307\sqrt{d-0\cdot1}}{\sqrt{s}-\text{L}\sqrt{s+1\cdot6}}-0\cdot3\sqrt{d-0\cdot1}=\text{vel. per sec.}$$

Diameter of Pipe.	Hydraulic Mean Depth of Conduit.		Log. A.	Viscidity C.	Hydraulic Mean Depth of Conduit.		Log. A.	Viscidity C.
Inches.	Inches.	Feet.	Logarithms.	Feet.	Inches.	Feet.	Logarithms.	Feet.
.4	.1	0.008	2.52105	0.30	12.0	1.00	3.71298	5.05
.8	.2	0.017	2.72683	0.50	15.0	1.25	3.76280	5.65
1.2	.3	0.025	2.83650	0.65	18.0	1.50	3.80338	6.20
1.6	.4	0.033	2.91240	0.80	21.0	1.75	3.83764	6.70
2.0	.5	0.041	2·96937	0.90	24.0	2.00	3.86725	7.20
2.4	.6	0.050	3.01515	1.00	27.0	2.25	3.89335	7.65
2.8	.7	0.058	3.05338	1.10	30.0	2.50	3.91667	8.05
3.2	.8	0.067	3.08616	1.20	33.0	2.75	3.93774	8.45
3 6	.9	0.075	3.11485	1.25	36.0	3.00	3.95696	8.85
4.0	1.0	0.083	3.14035	1.35	39.0	3.25	3.97463	9.20
4.8	1.2	0.100	3.18415	1.50	42.0	3.50	3.99998	9.55
6.0	1.5	0.125	3.23715	1.70	45.0	3.75	4.00619	9.90
7.2	1.8	0.150	3.28009	1.85	46.0	3.83	4.01104	10.00
8.0	2.0	0.167	3.30477	1.95	47.0	3.92	4.01579	10.15
8.4	2.1	0.175	3.31610	2.00	48.0	4.00	4.02042	10.25
9.6	2.4	0.200	3.34724	2.20	49.0	4.08	4.02496	10.35
10.8	2.7	0.225	3.37453	2.30	50.0	4.16	4.02940	10.45
12.0	3.0	0.250	3.39886	2.45	51.0	4.25	4 03377	10.55
13.2	3.3	0.275	3.42078	2.60	52.0	4.33	4.03805	10.65
14.4	3.6	0.300	3.44075	2.70	53.0	4.42	4.04224	10.75
15.6	3.9	0.325	3.45906	2.80	54.0	4.50	4.04635	10.85
16.0	4.0	0.333	3.46486	2.85	55 0	4.58	4.05040	10.95
16.8	4.2	0.350	3.47601	2.95	56.0	4.67	4.05436	11.05
18.0	4.5	0.375	3.49174	3.00	57.0	4.75	4.05825	11.15
19.2	4.8	0.400	3.50644	3.15	60.0	5.00	4.06954	11.50
20.6	5.1	0.425	3.52022	3.25	63.0	5.25	4.08027	11.75
21.6	5.4	0.450	3.53119	3.35	66.0	5.50	4.09055	12.03
22.8	5.7	0.475	3.54545	3.40	69.0	5.75	4.10027	12.30
24.0	6.0	0.500	3.55709	3.50	72.0	6.00	4.10962	12.55
25.2	6.3	0.525	3.56813	3.60	75.0	6.25	4.11859	12.85
26.4	6.6	0.550	3.57863	3.70	78.0	6.50	4.12720	13.10
27.6	6 9	0.575	3.58868	3.80	81.0	6.75	4.13550	13.35
28.8	7.2	0.600	3.59827	3.85	84.0	7.00	4.14349	13.60
30.0	7.5	0.625	3.60748	3.95	87.0	7.25	4.15119	13.85
31.2	7.8	0.650	3.61631	4.00	90.0	7.50	4.15862	14.05
32.4	8.1	0.675	3.62481	4.10	93.0	7 75	4.16582	14.30
33.6	8.4	0.700	3.63300	4.20	96.0	8.00	4.17258	14.55
34.8	8.7	0.725	3.64089	4.25	99.0	8.25	4.17953	14.75
36.0	9.0	0.750	3.64851	4.35	102.0	8.50	4.18648	14.95
37.0	9.3	0.775	3.65589	4.40	105.0	8.75	4.19362	15.15
38.0	9.6	0.800	3.66299	4.50	108.0	9.00	4.20095	15.35
39.6	9.9	0.825	3.66990	4.55	114.0	9.50	4.20800	15.55
40.0	10.0	0.833	3.67216	4.60	117.0	9.75	4.21577	15.75
44.0	11.0	0.916	3.69351	4.85	120.0	10.00	4.22576	15.95

TABLE VII.—FOR FINDING THE VELOCITY AND DISCHARGE, PER MINUTE, OF RIVERS, CANALS, AQUEDUCTS, PIPES, &c., CALCULATED FROM DE BUAT'S FORMULA,

$$\frac{307\sqrt{d - 0{\cdot}1}}{\sqrt{s} - \mathrm{L}\sqrt{s} + 1{\cdot}6} - 0{\cdot}3\sqrt{d - 0{\cdot}1} = \text{vel. per sec.}$$

Rat^e of Inclination 1 in	Log. B.	Rate of Inclination 1 in	Log. B.	Rate of Inclination 1 in	Log. B.	Rate of Inclination 1 in	Log. B.
1.0	9.71784	300	1.16035	2100	1.62325	6700	1.88898
1.5	9.81882	320	1.17612	2200	1.63403	6800	1.89233
2.0	9.88857	340	1.19092	2300	1.64432	6900	1.89564
2.5	0.94231	360	1.20490	2400	1.65414	7000	1.89891
3.0	0.98632	380	1.21806	2500	1.66358	7100	1.90214
3.5	0.02373	400	1.23048	2600	1.67261	7200	1.90532
4.0	0.05638	420	1.24232	2700	1.68133	7300	1.90845
4.5	0.08533	440	1.25360	2800	1.68971	7400	1.91154
5.0	0.11147	460	1.26433	2900	1.69780	7500	1.91458
5.5	0.13519	480	1.27461	3000	1.70558	7600	1.91757
6.0	0.15697	500	1.28445	3100	1.71313	7700	1.92052
6.5	0.17713	520	1.29391	3200	1.72042	7800	1.92344
7.0	0.19584	540	1.30300	3300	1.72750	7900	1.92632
7.5	0.21336	560	1.31172	3400	1.73135	8000	1.92916
8.0	0.22982	580	1.32015	3500	1.74099	8100	1.93179
8.5	0.24532	600	1.32830	3600	1.74716	8200	1.93475
9.0	0.25995	620	1.33614	3700	1.75373	8300	1.93749
9.5	0.27387	640	1.34370	3800	1.75984	8400	1.94020
10.0	0.28709	660	1.35108	3900	1.76578	8500	1.94286
15.0	0.39235	680	1.35823	4000	1.77159	8600	1.94551
20.0	0.46776	700	1.36513	4100	1.77725	8700	1.94811
25.0	0.52621	720	1.37185	4200	1.78277	8800	1.95069
30.0	0.57415	740	1 37839	4300	1.78814	8900	1.95324
35.0	0.61448	760	1.38471	4400	1.79339	9000	1.95576
40.0	0.64933	780	1.39089	4500	1.79851	9100	1.95826
45.0	0.67997	800	1.39690	4600	1.80352	9200	1.96073
50.0	0.70749	820	1.40277	4700	1.80875	9300	1.96317
55.0	0.73223	840	1.40674	4800	1.81321	9400	1.96539
60.0	0.75481	860	1.41408	4900	1.81790	9500	1.96797
65.0	0.78276	880	1.41953	5000	1.82249	9600	1.97033
70.0	0.79463	900	1.42487	5100	1.82699	9700	1.97267
75.0	0.81231	920	1.43005	5200	1.83142	9800	1.97497
80.0	0.82884	940	1.43515	5300	1.83573	9900	1.97726
85.0	0.84442	960	1.44011	5400	1.84002	10000	1.97952
90.0	0.85908	980	1.44498	5500	1.84421	11000	2.00099
95.0	0.87286	1000	1 44876	5600	1.84843	12000	2.02056
100.0	0.88593	1100	1.47223	5700	1.85237	13000	2.03855
120.0	0.93282	1200	1.49269	5800	1.85634	14000	2.05518
140.0	0.97109	1300	1.51148	5900	1.86022	15000	2.07065
160.0	1.00466	1400	1.52885	6000	1.86404	16000	2.08512
180.0	1.03410	1500	1.54497	6100	1.86778	17000	2.09869
200.0	1.06026	1600	1.56014	6200	1.87146	18000	2.11148
220.0	1.08390	1700	1.57416	6300	1.87507	19000	2.12347
240.0	1.10542	1800	1.58747	6400	1.87864	20000	2.13503
260.0	1.12523	1900	1.60004	6500	1.88213	22000	2.15633
280.0	1.14345	2000	1.61195	6600	1.88558	24000	2.17533

TABLE VIII.—FOR FINDING THE VELOCITY AND DISCHARGE OF WATER THROUGH SLUICES, ETC.

Head of Water.	Natural Velocity per second	Effective Velocity per second	Discharge per min. through 1 ft. square.
0.25	4.000	2.500	150.00
0.50	5.656	3.545	212.10
0.75	6.928	4.330	259.80
1.00	8.000	5.000	300.00
1.25	8.944	5.590	335.40
1.50	9.797	6.120	367.20
1.75	10.582	6.615	399.00
2.00	11.312	7.070	424.20
2.25	12.000	7.500	450.00
2.50	12.648	7.905	474.30
2.75	13.266	8.290	497.40
3.00	13.856	8.660	519.60
3.25	14.421	9.015	540.90
3.50	14.965	9.355	561.30
3.75	15.492	9.680	580.80
4.00	16.000	10.000	600.00
4.25	16.492	10.310	618.60
4.50	16.970	10.605	636.30
4.75	17.435	10.895	653.70
5.00	17.888	11.180	670.80
5.25	18.330	11.455	687.30
5.50	18.761	11.725	703.50
5.75	19.183	11.990	719.40
6.00	19.595	12.245	734.70
6.25	20.000	12.500	750.00
6.50	20.396	12.745	764.70
6.75	20.784	12.990	779.40
7.00	21.165	13.230	793.80
7.25	21.540	13.465	807.90
7.50	21.908	13.693	821.58
7.75	22.270	13.920	835.20
8.00	22.627	14.140	848.40
8.25	22.978	14.360	861.60
8.50	23.323	14.577	874.62
8.75	23.664	14.790	887.40
9.00	24.000	15.000	900.00
9.25	24.330	15.206	912.36
9.50	24.656	15.411	924.66
9.75	24.980	15.612	936.72
10.0	25.298	15.811	948.66
10.5	25.920	16.200	972.00
11.0	26.528	165.80	994.80
11.5	27.128	16.955	1017.30
12.0	27.712	17.320	1039.20
12.5	28.264	17.650	1059.00
13.0	28.840	18.025	1081.50
13.5	29.360	18.350	1101.00
14.0	29.928	18.705	1122.30
14.5	30.480	19.050	1143.00
15.0	30.976	19.360	1161.60

TABLE IX.—FOR CHANGING CUBIC FEET OF WATER INTO IMPERIAL GALLONS AND HOGSHEADS.

Cubic Feet.	Gallons.	Hogsheads.
1	6.23	0.09892
2	12.46	0.19784
3	18.69	0.29676
4	24.92	0.39568
5	31.16	0.49460
6	37.39	0.59352
7	43.62	0.69244
8	49.85	0.79136
9	56.08	0.89208
10	62.32	0.98920
20	124.64	1.97840
30	186.96	2.96760
40	249.28	3.95680
50	311.60	4.94600
60	373.92	5.93520
70	436.24	6.92440
80	498.56	7.91360
90	560.89	8.90280
100	623.21	9.89200
200	1.246.40	19.7840
300	1,869.60	29.6760
400	2,492.80	39.5680
500	3,116.10	49.4600
600	3,739.20	59.3520
700	4,362.40	69.2440
800	4,985.60	79.1360
900	5,608.90	89.0280
1,000	6,232.10	98.9200
2,000	12,464.00	197.840
3,000	18,696.00	296.760
4,000	24,928.00	395.680
5,000	31,160.00	494.600
6,000	37,392.00	593.520
7,000	43,625.00	692.440
8,000	49,857.00	791.360
9,000	56,089.00	890.280
10,000	62,322.00	989.200
20,000	124,642.00	1,978.40
30,000	186,960.00	2,967.60
40,000	249,284.00	3,956.80
50,000	311,600.00	4,946.00
60,000	373,927.00	5,935.20
70,000	436,250.00	6,924.40
80,000	498,569.00	7,913.60
90,000	560,890.00	8,902.80
100,000	623,212.00	9,892.00
200,000	1,246,424.00	19,784.0
300,000	1,869,636.00	29,676.0
400,000	2,492,848.00	39,568.0
500,000	3,116,060.00	49,460.0

TABLE X.—SHOWING THE DISCHARGE, IN CUBIC FEET, PER MINUTE, THROUGH PIPES RUNNING HALF FULL.

Diameter of Pipe, in inches.	Rate of Inclination 1 in									
	10	20	30	40	50	60	70	80	90	100
1.0	0.84	0.55	0.43	0.36	0.32	0.28	0.26	0.23	0.21	0.20
1.6	2.74	1.92	1.52	1.25	1.09	0.97	0.90	0.82	0.76	0.72
2.4	8.31	5.37	4.24	3.57	3.11	2.78	2.53	2.33	2.17	2.04
2.8	12.3	8.12	6.33	5.31	4.63	4.14	3 76	3.47	3.23	3 03
3.2	17.4	11.4	8.91	7.47	6.52	5.83	5.30	4.89	4.55	4.26
3.6	23.4	15.4	12.0	10.1	8.82	7.88	7.17	6.61	6.15	5.77
4.0	30.8	20.2	15.7	13.2	11.5	10.3	9.40	8.66	8.06	7.56
4.4	39.3	25.8	20.1	16.8	14.7	13.1	11.9	11.0	10.2	9.65
4.8	49.1	32.2	25.1	21.0	18.3	16.4	14.9	13.7	12.8	12.0
5.2	60.2	39.5	30.8	25.8	22.5	19.1	18.3	16.9	15.7	14.7
5.6	72.7	47.7	37.2	32.2	27.2	24.3	22.1	20.4	19.0	17.8
6.0	86.6	56.9	44.3	37.2	32.4	29.0	26.4	24.3	22.6	21.2
7.0	137.	87.9	68.6	57.4	50.4	44.8	40.9	37.8	35.0	33.2
8.0	180.	118.	92.0	77.2	67.4	60.0	54.8	50.6	47.0	44.2
9.0	242.	159.	124.	104.	90.9	81.0	72.9	68.4	63.4	59.4
10.0	317.	208.	162.	136.	118.	106.	96.5	89.0	82.7	77.7
11.0	403.	265.	206.	173.	151.	135.	122.	113.	105.	98.6
12.0	503.	330.	257.	216.	188.	168.	153.	141.	131.	127.
15.0	886.	580.	453.	380.	331.	297.	269.	248.	232.	216.
18.0	1399.	920.	718.	602.	525.	470.	417.	394.	367.	344.

TABLE XI.—OF HYDRAULIC EQUIVALENTS.

No.	Depth of Water, in Feet and Inches.									No.
	6.0	5.6	5.0	4.6	4.0	3.6	3.0	2.6	2.0	
1	...	...	...	...	...	...	...	2	3½	1
2	...	...	...	...	...	...	2	3½	6	2
3	...	...	...	...	...	2	3½	5½	8½	3
4	...	...	...	...	2	3½	5	7	11	4
5	...	...	...	2	3	4½	7	9	14	5
6	...	...	2	3	4½	6	9	12	17	6
7	...	2	3	4½	6	8	10	15	21	7
8	2	3	4½	6	8	10	14	19	26	8
9	3	4	6	7	10	13	16	23	30	9
10	4	5½	7	9	11	15	19	26	34	10
11	5	6½	8½	10	13	17	22	28	39	11
12	6	8	10	12	15	19	24	31	45	12
13	7	9	11	13½	17	20	26	34	48	13
14	8	10	12	15	18½	22	28	38	53	14
15	9	11	13½	16	20	24	31	42	57	15
16	10	12	14½	18	22	26	34	45	60	16
17	11	13½	16	19½	24	29	37	48	65	17
18	12	14½	17½	23	27	31	40	51	70	18

The Vertical Columns contain the Breadths of Conduit or River.

Table XII.—For Finding the Velocity in Miles, per Hour.

Velocity in Feet per minute.	Velocity in Miles, per hour.	Velocity in Feet per minute.	Velocity in Miles, per hour.
Feet.	Miles.	Feet.	Miles.
1	0.0114	330	3.7488
2	0.0227	340	3.8624
3	0.0341	350	3.9760
4	0.0455	360	4.0896
5	0.0568	370	4.2032
6	0.0681	380	4.3168
7	0.0795	390	4.4304
8	0.0910	400	4.5440
9	0.1024	410	4.6576
10	0.1136	420	4.7712
11	0.1250	430	4.8848
12	0.1364	440	4.9984
13	0.1478	450	5.1120
14	0.1592	460	5.2256
15	0.1706	470	5.3392
16	0.1820	480	5.4528
17	0.1934	490	5.5664
18	0.2048	500	5 6800
19	0.2162	510	5.7931
20	0.2272	520	5.9072
30	0.3409	530	6.0208
40	0.4554	540	6.1344
50	0.5682	550	6.2480
60	0.6819	560	6.3616
70	0.7955	570	6.4752
80	0.9108	580	6.5888
90	1.0238	590	6.7024
100	1.1375	600	6.8140
110	1.2500	610	6.9296
120	1.3640	620	7.0432
130	1.4780	630	7.1568
140	1.5920	640	7.2704
150	1.7060	650	7.3840
160	1.8200	660	7.4978
170	1.9340	670	7.6112
180	2.0480	680	7.7248
190	2.1620	690	7.8384
200	2.2720	700	7.9520
210	2 3866	710	8.0656
220	2.4992	720	8.1792
230	2.6128	730	8.1928
240	2.7264	740	8.3065
250	2.8400	750	8.4200
260	2.9536	760	8.5336
270	3.0672	770	8.6472
280	3.1808	780	8.7608
290	3.2944	790	8.8744
300	3.4080	800	8.9880
310	3.5216	900	10.2285
320	3.6352	1000	11.3650

Table XIII.—Gradients or Inclined Planes.

Ascent or Descent in one mile.	Rate of inclination.	Ascent or Descent in one mile.	Rate of inclination.
Feet.	1 in	Feet.	1 in
1	5280.0	51	103.5
2	2640.0	52	101.5
3	1760.0	53	99 6
4	1320.0	54	97.8
5	1056.0	55	96.0
6	880.0	56	94.3
7	754.3	57	92.6
8	660.0	58	91.0
9	586.7	59	89.5
10	528.0	60	88.0
11	480.0	61	86.6
12	440.0	62	85.2
13	406.1	63	83.8
14	377.1	64	82.5
15	352.0	65	81.2
16	330.0	66	80.0
17	310.6	67	78.8
18	293.3	68	77.6
19	277.9	69	76.5
20	264.0	70	75.4
21	251.4	75	70.4
22	240.0	80	66.0
23	229.6	85	62.1
24	220.0	90	58.7
25	211.2	95	55 6
26	203.1	100	52.8
27	195.6	110	48.0
28	188.6	120	44.0
29	182.1	130	40.6
30	176.0	140	37.7
31	170.3	150	35 2
32	165.0	160	33.0
33	160.0	170	31.1
34	155.3	180	29.3
35	150.9	190	27.8
36	146 7	200	26.4
37	142.7	220	24.0
38	138.9	240	22.0
39	135.4	260	20.3
40	132 0	280	18.9
41	128.8	300	17.6
42	125.7	320	16.5
43	122.8	340	15.3
44	120.0	360	14.7
45	117.3	380	13.9
46	114.8	400	13.2
47	112.3	425	12.4
48	110.0	450	11.7
49	107.8	475	11.1
50	105.6	500	10.6

TABLE XIV.—OF SUPERFICIAL, MEAN, AND BOTTOM VELOCITIES—*Vide* p. 30.

Velocity in Feet, per minute.	Superficial Velocity in Miles.	Velocity in Feet, per minute.	Velocity in Feet, per minute.	Velocity in Feet, per minute.	Superficial Velocity, in Miles.	Velocity in Feet, per minute.	Velocity in Feet, per minute.
Surface.	Per Hour.	Mean.	Bottom.	Surface.	Per Hour.	Mean.	Bottom.
5	0.0568	2.50	0.00	255	2.8978	221.78	188.56
10	0.1136	5.40	0.86	260	2.9546	226.41	192.82
15	0.1704	8.84	2.68	265	3.0114	231.10	197.19
20	0.2272	12.50	5.00	270	3.0682	235.71	201.42
25	0.2840	16.31	7.63	275	3.1250	240.41	205.83
30	0.3408	20.25	10.50	280	3.1818	245.04	210.08
35	0.3976	24.27	13.55	285	3.2386	249.92	214.84
40	0.4544	28.35	16.71	290	3.2954	254.43	218.86
45	0.5112	32.50	20.00	295	3.3522	259.09	223.18
50	0.5680	36.68	23.37	300	3.4090	263.77	277.55
55	0.6248	40.92	26.89	305	3.4658	268.44	231.88
60	0.6816	45.18	30.40	310	3.5226	273.15	236.30
65	0.7384	49.47	33.93	315	3.5794	277.84	240.68
70	0.7952	53.78	37.57	320	3.6362	282.50	245.00
75	0.8520	58.11	41.27	325	3.6930	287.18	249.36
80	0.9088	62.50	45.00	330	3.7498	291.88	253.76
85	0.9656	66.88	48.77	335	3.8066	296.60	258.20
90	1.0224	71.16	52.32	340	3.8634	301.26	262.23
95	1.0792	75.71	56.42	345	3.9202	305.98	266.96
100	1.1360	80.13	60.27	350	3.9770	310.68	271.37
105	1.1928	84.18	63.37	355	4.0338	315.36	275.73
110	1.2496	89.04	68.08	360	4.0906	320.06	280.13
115	1.3064	93.51	72.01	365	4.1474	324.66	284.31
120	1.3632	97.99	75.97	370	4.2042	329.48	288.95
125	1.4200	102.50	80.00	375	4.2610	334.22	293.44
130	1.4768	107.01	84.01	380	4.3178	338.92	297.84
135	1.5336	111.51	88.03	385	4.3766	343.63	302.26
140	1.5904	116.05	92.11	390	4.4314	348.35	306.70
145	1.6472	120.57	96.14	395	4.4882	353.03	311.05
150	1.7040	125.11	100.22	400	4.5460	357.77	315.54
155	1.7608	129.62	104.29	405	4.6028	362.50	320.00
160	1.8176	134.20	108.36	410	4.6596	367.21	324.42
165	1.8744	138.77	112.53	415	4.7164	371.95	328.90
170	1.9312	143.30	116.62	420	4.7732	376.63	333.26
175	1.9880	147.92	120.84	425	4 8300	381.42	337.84
180	2.0448	152.50	125.00	430	4.8868	386.15	342.30
185	2.1016	157.07	129.14	435	4.9436	390.85	346.70
190	2.1584	161.67	133.34	440	5.0004	395.56	351.12
195	2.2152	166.28	137.57	445	5.0572	400.33	355.66
200	2.2720	170.86	141.73	450	5.1140	405.03	360.06
205	2.3288	175.48	145.96	455	5.1708	409.79	364.58
210	2.3856	180.07	150.15	460	5.2276	414.47	368.94
215	2.4424	184.70	154.40	465	5.2844	419.30	373.60
220	2.4992	189.36	158.71	470	5.3412	424.01	378.02
225	2.5560	193.35	162.91	475	5.3980	428.77	382.25
230	2.6138	198.58	167.16	480	5.4543	433.43	386.85
235	2.6706	203.23	171.47	485	5.5116	438.26	391.53
240	2.7274	207.85	175.76	490	5.5684	442.98	395.96
245	2.7842	212.50	180.00	495	5.6252	447.80	400.60
250	2.8410	217.14	184.29	500	5.6820	452.50	405.00

SECTION XIV.

POWER OF MAN AND HORSE.

THE ordinary method of computing mechanical effect or power of Machinery, is by ascertaining the *weight* raised to a certain *height* in a given *time;* the product of these quantities constitutes what is called the *Mechanical force* or *Mechanical effect.*

Thus if 12 cubic feet of water, each 62½ lbs. avoirdupois, were to be raised one foot in a second, it would require a force of 12 × 62½ = 750 lbs. and if this force continued, it would be 750 × 60 = 45,000 lbs. per minute raised one foot high, and this is the amount of expenditure of water that is usually reckoned a horse power, viz., 12 cubic feet per second falling one foot. The excess above the amount stated in the following Table being taken as for waste and overcoming friction of the wheels.

The horses' power is principally used by Engineers in this country as a *Dynamic* unit, because this power is familiar, from its being constantly under observation in the carriage of loads, and propulsion of Machinery. The following Table exhibits the relative power of MAN and Horse, as taken from the best authorities.

RELATIVE POWER OF MAN AND HORSE.

Manner of Application of Power.	Force in lbs. avoirdupois.	
	At 220 feet per minute.	At 1 foot per minute.
A MAN is able to *carry*	27.27	6,000
To turn the wench of a crane ...	28.63	6,300
To exert in the act of *pumping*	17.33	3,814
In the act of *ringing*	38.95	8,750
In the act of rowing	40.95	9,010
A HORSE power is equal to ...	150.00	33,000

Dr. T. Young assumes the *mean effect* of labour of an active man walking to the greatest possible advantage to be 10 lbs. raised 10 feet per second, for 10 hours per day, or 100 lbs. raised 1 foot in a second.

The following useful *formula* of Euler's elegantly expresses the power or force of Traction of an ordinary man moving with different velocities, $2(6-v)^2=F$, in which F represents the force of Traction in pounds, and v the velocity of a man in miles, which affords the following

Rule.—*Take the velocity of a man from* 6 *and double the square of the remainder will be the force of* Traction *in lbs. avoirdupois.*

Hence the following Table :—

Velocity of man per hour in miles,	0	1	2	3	4	5	6
Corresponding force of Traction, in lbs.	72	50	32	18	8	2	0

Which shows that a man *walking* 2 miles per hour has a power of Traction of 32 lbs., which is his maximum useful effect.

Now, the permanent force of a *horse*, according to Leslie,* Smeaton, and Coulomb, is that of 5 men working 10 hours a-day. Tredgold states a horse power to be equal to 6 men, the rate of travelling being 8 hours per day. Watt found from repeated experiments that a horse moving at 2½ miles per day will rise 150 lbs., or 33,000lbs. 1 foot high per minute, although he allows 44,000 lbs. for a horse power in his steam engines, considering the difference as due to the Friction. The following formula of Euler's will give the useful or effective power of a Horse in drawing $(12-v)^2=$ Force in lbs. avoirdupois, which affords the following results :—

Miles per hour,	0	1	2	3	4	5	6	7	8	9	10	11	12
Force of Traction,	144	121	100	81	64	49	36	25	16	9	4	1	0

The upper horizontal column of which shows the velocity of a horse in miles per hour, and the lower the corresponding force of Traction in lbs.; from which we learn that the greatest useful effect is produced when the horse moves at the rate of 4 miles per hour, his power of traction being then 6 lbs., or nearly 22,000 lbs. raised 1 foot high per minute. The following table, taken from Tredgold, will show the maximum quantity of labour which a horse of average strength is capable of performing, whether on a Canal, Railway, or common level Road :—

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* *Vide* "Leslie's Natural Philosophy," pp. 275–288.

Velocities per hour.	Day's Work.	Force of Traction. Constant.	Useful effect per day, for a distance of one mile on a		
			Canal.	Horizontal Railway.	Level Road.
Miles.	Hours.	Lbs.	Tons.	Tons.	Tons.
2.5	11.50	83.3	520.0	115.0	14.0
3.0	8.00	83.3	243.0	92.0	12.0
3.5	5.90	83.3	153.0	82.0	10.0
4.0	4.50	83.3	102.0	72.0	9.0
5.0	2.90	83.3	52.0	57.0	7.2
6.0	2.00	83.3	30.0	48.0	6.0
7.0	1.50	83.3	19.0	41.0	5.1
8.0	1.12	83.3	12.8	36.9	4.5
9.0	0.90	83.3	9.0	32.0	4.0
10.0	0.75	83.3	6.6	28.8	3.6

SECTION XV.

OF WATER APPLIED TO MILLS AS A MOTIVE POWER.

Water being a most powerful and useful agent in producing power or motion in Machinery, its capabilities have been frequently calculated; but the variation in the horse power, as stated or laid down by several authorities, being different, the horse power attributed to water will, in consequence thereof, vary. **Waterwheels** are distinguished from the manner in which the water is made to act as an impelling power. When it acts by its weight, it is brought over the wheel and laid on the opposite sides, in which case it is termed an *overshot* wheel. When the water acts by its impulse, and strikes the wheel below the centre, it is then termed an *undershot* wheel. It frequently happens, from various causes—but, principally, from want of sufficient fall—that the water is made to strike the wheel somewhere between the centre and vertex, in which case it is termed a *breast* wheel, which may be said to be compounded of the other two. Thus, fig. 16 is a representation of an undershot wheel, which may be converted into an overshot wheel, if we conceive the water to strike it in a tangential direction at A, and to have buckets of a peculiar construction attached to the circumference, to retain the water until it has descended to the lowest possible point; and when the water enters at B, it is termed a Breast Wheel, in which case it is also provided with suitable Buckets, the contour of which has been a fruitful source of contention amongst Engineers, Millwrights, &c., they should partake of the *Cycloidal* form, being the curve of quickest descent.—*Vide* p. 75.

When the water is made to act by its weight, as in an overshot wheel, it is delivered from the sluice or spout as *high* on the wheel *as possible*, that it may, by its force and gravity, the more effectually press it down; and when the water is made to strike an undershot wheel, it is delivered *as low as possible*, that it may have acquired the greatest force and velocity attainable at the moment it impinges against the floatboard of the wheel. The adoption of these mills will, in a great measure, depend on the fall of water that can be obtained. Mr. Lambert recommends the erection of an undershot wheel where the fall is under 4 feet, and an overshot wheel when the fall exceeds 10 feet, of a breast wheel where the fall is between 4 and 10 feet, provided that there be a sufficiency of water—a point never to be overlooked in the selection of mill-sites, when the machinery is to be propelled by water as a motive power. Happily in this country we are provided with an incalculable amount thereof, as shown by that eminent writer, Sir ROBERT KANE, in his celebrated work on "The Industrial Resources of Ireland," in which we may clearly perceive a splendid and *practical* example of that industry which he so earnestly recommends to his Country.

Speaking of the available power of the waters of Ireland he says, page 70 :—

> "I am most anxious to avoid every source of error in excess, even at the risk of falling into the opposite extreme. I shall consider the mountainous regions of the north, the west, and south, as adding to the height of the central plain but 150 feet, and assume as the average height of the surface of Ireland 450 feet. That is to say, the water which flows in our rivers to the sea has an average fall of 150 yards, and now finally we may calculate the total water power of Ireland. We had for the total quantity of rain falling in a year 100,712,031,640 cubic yards; of this, one-third flows to the sea, that is 33,237,343,880 cubic yards; or, for each day of twenty-four hours 91,061,216 cubic yards, weighing 68,467,100 tons. This weight falls from 150 yards, and as 884* tons falling 24 feet in 24 hours is a horse power, the final result is, that, in average, we possess, distributed over the surface of Ireland a water power capable of acting night and day, without interruption, from the beginning to the end of the year, and estimated at the force of 3,227 horse power per foot of fall, or for the entire average fall of 450 feet, amounting to 1,452,150 horse power. But mechanical power is never thus intermittingly driven, and if we reduce the force to the year's work of 300 working days of twelve hours each,

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* In this calculation Dr. Kane allows only 33,000 lbs. as the horse power. Mr. Fairbairn, whom he subsequently quotes, in p. 91, allows 45,000 lbs. as a working horse power, viz., 12 cubic feet per second falling one foot. That difference arises, as already stated, from the power attributed to a horse.—ED.

we find it to represent 3,533,565 horse power, that is more than three million and a half of horse power."

And in page 76 he estimates the power of that noble river, the Shannon, to be, from the mouth of Lough Allen to Meelick, equal to a power of 4,717 horses, and from Killaloe to Limerick, with a fall of 97 feet, a power equal to 33,950 horses, making a total of horse power of 38,667 horses, when supposed to be in continued action.

Mr. MacMahon, in his Report of Lough Neagh, already noticed in page 76, states that its Catchment Basin amounts to 1,865 square miles, the extent of the lake itself being 153½ square miles, he thus sums up the available horse power of the Lower Bann River, the only outlet from the Lake—

"It has been already stated, that the average discharge from Lough Neagh during summer, is 100,000 cubic feet per minute, and that in winter it is something under 400,000 cubic feet.

"This vast motive power, the bountiful gift of nature, is here offered on a scale of unequalled greatness, to those whose enterprising spirit may promote and bring to maturity this truly national and beneficent measure.

"A feature of great interest in the natural formation of the Lower Bann, and one of great value in the proposed measures of improvement, is the distribution of the falls of the river, into four distinct and convenient divisions, each easy of access; that is Portna, near Kilrea, Movanagher, Carnroe, and the Salmon-leap, near Coleraine. In addition to the power concentrated at these points, a fluctuating power of some extent may be obtained at Toome Bar, but it is not taken credit for in the estimate.

"The first and principal fall, therefore (omitting that at Toome Bar) is at Portna, amounting to 14½ feet. The effective fall for mill-power is taken at 13 feet; but as I am not called upon by the Board's instructions to offer any engineering opinion, as to the best or most productive mode of applying the whole of the hitherto latent power generated in the great basin of Lough Neagh, I leave the investigation of that portion of the subject to the parties who may hereafter require to use it, and for the security of those *now interested*, I have had our calculations based on the minimum amount of power, we shall at all times derive from the summer discharge of the Lough, namely, 100,000 cubic feet per minute. This constant quantity will create a power equal to 189 horses per foot of fall; estimating the Dynamic unit at 33,000* the whole power obtained at the Portna fall will therefore be 2,457 horses, equal to the work of 24 manufactories requiring each the power of 102 horses, for 24 *hours per day*. Should, however, the time for working in factories be limited to 12 hours per day, it may be a desirable object to preserve the water, that would otherwise run to waste during the night, or when work was suspended.

"The discharge from Lough Neagh during the 12 hours of night, or by the suspension of work as assumed in the factories, will amount to 72,000,000 cubic feet, and would raise the surface of Lough Beg and the River as above referred to, 6 inches. It follows, that if a simple moveable contrivance were adopted for adding 6 inches to the height of the regulating weir at Portna, *when required*, all the water, amounting to 72,000,000 of cubic feet, produced by the continual discharge of 100,000 cubic feet per minute from the Lough, during the 12 hours of cessation from work, may be conserved, and the power available in the working hours doubled in effect; that is, made equivalent to the work of 48 steam-engines of 102 horse-power each, for 12 hours per day.

"At Movanagher, the fall will be 8½ feet, equal to 1,606 horses. At Carnroe and the Salmon-leap, the effective falls will be 5 feet respectively, and equal to 945 horses each. The falls on the river being in succession, the proposed conserving process would have the same influence on all as it has at Portna.

"The available power, therefore, on the whole of the Lower Bann River (according to the foregoing statement), would be equal to 120 steam-engines of 100 Bolton and Watt's estimated horse-power each, for 12 hours per day, independent of the surplus water which may be economised during winter, and likewise independent of any aid from Lough Neagh as a reservoir. Should, however, the demand for power become greater than the supply stated would accommodate, Lough Neagh may be made to furnish means so ample as to be far beyond the reach of useful exhaustion.†

"The average rate paid at the Shaw's Water Works, near

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* This amount of Horse power is a third less than that stated in page 94, and consequently the horse power stated here will be proportionally greater.—Ed.

† 12 inches on the Lough would contain nearly 4,400 millions cubic feet of water.

Greenock, for motive power, is £2 15s. per horse-power; but suppose it to be let on the Lower Bann at £1 15s. per horse (the difference amply compensating for any supposed advantage from situation), it would, when fully occupied on these terms, produce a rental equal to £21,000 per annum. Say for work of 12,000 horses.

"If attention be directed to the neighbouring districts of the Upper Bann and the River Lagan, it will be found, from the value there set on mill-power, and the care taken to economise its use, in situations greatly inferior to those on the Lower Bann, that there is little speculation in the anticipation, that the day is not remote when the whole of the power enumerated will be let at a sum fully equal to that above stated; particularly when we know that steam-power, at the very lowest estimated rate, costs twelve times as much as water power is here valued at.

"Statements such as we now make, cannot fail to excite surprise, when it is seen that water-power of such extent and value has been permitted to run to waste up to the present moment, without producing a single shilling of profit to man, or in any way assisting the productive industry of the country.

"Here, Providence has performed, in the most perfect and ample manner, what would otherwise require from man much skill to direct, and such an immense amount of labour and expense to execute, as would in a great measure neutralize its benefits. All that is required in this district, is to aid nature by the removal of the existing impediments which check the free discharge of the waters through the Lower Bann, and skilfully to direct her energies so as to generate mechanical power, at the points most suited to the location of manufacturing establishments."

Mr. Smeaton has paid particular attention to this subject of mill power, and, after a series of experiments conducted with the greatest care and attention, he deduced the following principles, which he calls Maxims.

UNDERSHOT WHEELS.

Maxim I.—"That the virtual head of water being the same, the effect will be nearly as the quantity of water expended." Or, in other words, the head of water being the same, the effect will be proportional to the sectional area of the stream or sluice through which it passes.

Maxim II.—The expense of water being the same the expense will be nearly as the height of the virtual or effective head.

Maxim III.—That the quantity of water expended being the same the effect is nearly as the square of its velocity. And,

Maxim IV.—The aperture being the same, the effect will be nearly as the cube of the velocity of the water.

He has also shown that the ratio between the power and effect of an undershot wheel is as 10 to 3.18, and that the velocity of the circumference of the wheel should half the velocity of the stream, and that the float boards should rise perpendicularly out of the water which is the position of least resistance. For

OVERSHOT WHEELS,

He shows that the ration of the power to the effect is as 10 to 6.6 when water is delivered above the apex of the wheel, and is computed from the whole height of the fall, but as 10 to .8, if computed from the height of the wheel, and, consequently, that the effect of an overshot wheel will be double that of an undershot under the same circumstances and fall.

He was once of opinion that the periphery of the overshot wheel should move with a velocity of three feet per second, but from further examination into the effects, he subsequently ascertained that it may range from 6½ to 8½ feet per second, and that the higher the wheel is, in proportion to the whole descent, the more effective will it be, and, in general, it will be found that the effective power of these wheels will be jointly proportional to the perpendicular height and quantity of water expended, that is to their product.

BREAST WHEELS,

He found their effect to be that of an undershot wheel whose head of water is equal to the difference of level between the surface of the water in the reservoir, and the part where it strikes the wheel *added* to that of an overshot wheel, whose height is equal to the difference of level between the part where it strikes and the level of the tailwater.

Having stated these principles, deduced from the best authorities, we shall now proceed to give examples in each case, and show how the tables may be useful in expediting and simplifying the operations, previous to which the following examples will be found useful.

The resistance a body sustains in passing through a stream is proportional to the square of the velocity, and the amount of this resistance is equal to a column of water having the same plane for its base and a height equal to the height which a body should fall from in free space to acquire the velocity of the stream.

Thus, resuming the former notation, p. 77, we have $h = \left(\frac{v}{8}\right)^2$ which, in the case of a stream corresponds, very nearly to one pound for every square foot of obstacle, multiplied by the square of the velocity in feet per second. Thus, let *a* denote the area of the opposing surface, then will $\frac{62\frac{1}{2}}{64} av^2$ accurately express the shock or impulse; and if the stream consist of sea water, the fractional co-efficient may be omitted, and av^2 would represent the impelling force.* For

Example.—A mill race 3 feet broad, 2 feet deep, and running at the rate of 4 miles per hour, or 352 feet per minute, would communicate an impression equal to the fall through .538 of a foot, being the head due to the given velocity, as may be found in Table No. 8, and the total force per minute will be $3 \times 2 \times 352 \times 26\frac{1}{2} \times .538 = 70{,}966$ lbs., which, being incessant, will amount to the power of 100 men.—See page 94.

If the velocity be given in miles per hour, it would be sufficiently accurate; allow two pounds for every square foot of opposing surface, multiplied into the square of the velocity of the stream, as will be explained in example No. 3 of the following section.

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* *Vide* "Leslie's Philosophy Hydrostatics," pp. 425–8.

SECTION XVI.

TO FIND THE FORCE OF WATER DIRECTLY IMPINGING AGAINST A PLANE SURFACE.

Rule.—*Multiply the area of the surface in square feet by the velocity of the water in feet per second and 39-40th thereof will be the force in pounds avoirdupois.*

Hence the following results:—

Velocity in feet per second	1	2	3	4	5	6	7	8	9	10
Force in lbs. avoirdupois,	1	4	9	15½	24⅜	35	48¾	62½	79	27½

Example I.—Given the velocity of a stream 15 feet per second, what will be its force on a plane 10 feet by 2?

$10 \times 2 = 20 =$ area of surface
$15^2 = 225$ square of velocity

1-40)4500
Deduct 112½

4437½ lbs. the force required.

When the velocity is given in feet per minute, as shown in Table No. 2, multiply the area by the square of the velocity and the product, divided by 60, and deduct 1-40th thereof, and the remainder will be the force in pounds avoirdupois.

Example II.—A rectangular board, 4 feet long and 2 feet broad, was placed in a river 10 feet broad, 4 feet deep, and having a fall of 1 foot per mile, what will be the resistance or force of water impinging directly against it?

In *Auxiliary* Table No. 3, corresponding to the given dimensions of the River, will be found 138 the velocity of the water per minute—therefore

$138^2 = 19044$
Area of board $4 \times 2 = 8$

60)152352 = 2539·2
1-40th 63·48

2475.72 the resistance.

Now by examining Auxiliary Table, No. 3, we find the given mean velocity corresponding to 4 feet deep and 1 foot fall per mile, consequently a river with this depth and fall would give the resistance found—and if we want the *superficial* or bottom velocity of this river look for the mean velocity 138 in Table No. 14, and corresponding will be found 114 and 91, the mean and bottom velocities.

If the velocity is given in miles per hour, multiply the area of the opposing surface, in square feet, by the square of the velocity, and double the product, added to 1-20 thereof, will be the force in lbs. Hence the following results :—

Velocity in Miles per hour	1	2	3	4	5	6	7	8	9	10
Force in lbs. on 1 square ft.	2.1	8.4	18.9	33.6	52.5	75.6	102.9	134.4	170.1	210

Example III.—What will be the force of water, moving at 5 miles per hour, against a plane surface 10 feet long and 6 broad?

$5^2 = 25$ the square of the velocity,
60 the area of surface,

$1500 \times 2 = 3000$
Deduct 1-20th 150

3,150 lbs. the force required.

Example IV.—What will be the maximum velocity of an undershot wheel when propelled by a fall of water 4 feet high? $\sqrt{4} = 2 \times 8 = 16$ feet, the velocity of the water, half of which, 8, will be the velocity of the wheel per second.

Example V.—What head of water will produce a velocity of 8 feet per second in an undershot wheel?
$8 \times 2 = 16$ the velocity of the water and
$16 \div 8 = 2$ and $2^2 = 4$ the head of water required.

To perform this by Table No. 8, double the velocity of the wheel, and look for the No. in the 2nd column, opposite to which will be found 4, the head required.

Example VI.—What velocity would a stream 10 feet wide and 3 feet deep communicate to an undershot wheel, when the fall per mile is 9 feet? By Table No. 2 we find the mean velocity 363 feet per minute or 6 feet per second, half of which will be the velocity of the wheel.

GENERAL RULE FOR FINDING THE HORSE POWER OF STEAM.

From what has been explained in the foregoing observations, particularly Section 12, and Tables 2 and 8, for showing the velocity of water in Rivers, through

Sluices, &c., it will not be difficult to ascertain the horse power of any mill.

Taking 44,000 lbs. falling 1 foot per minute, as the average amount of horse power, which may be represented by *h*, and let the fall be *f*, the discharge per minute D and let *m* represent the weight of one cubic foot of water, then will

$\frac{Dfm}{h} = H$, express the horse power, of any stream and $D = \frac{Hh}{mf}$

the requisite discharge for any given horse power—the values of D. and *f* can be had from Tables No. 2 or 8, and *h* and *m* are constant, from whence we readily infer the following rule:—

Rule.—*Multiply the weight of water expended, per minute, by the effective perpendicular descent, and divide the product by* 44,000, *the estimate of a horse power, and the quotient will be the horse power required.*

Example VII.—The discharge per minute is 960 cubic feet, with a fall of 11 feet, what horse power is it equal to?

$$\frac{62\frac{1}{2} \times 11 \times 960}{44000} = 15 \text{ the horse power.}$$

In estimating the power of a water-wheel, half the head should be added to the whole fall, and the sum called the effective perpendicular descent. For 1 foot fall is nearly equal to 2 feet head—thus the velocity for 1 foot fall will be $\sqrt{1} \times 8 = 8$ and that for 2 feet head $\sqrt{2} \times 5.4 = 7.7$ nearly, as above.

Given 20 cubic feet of water per second, applied to an overshot wheel having 2 feet head of water, and 8 feet fall, required the horse power.

2)2 = 1 + 8 = 9 effective fall, 20 cubic ft. per second
60
1200 = per minute
9 effective fall

$$\frac{62\frac{1}{2} \times 10800}{44000} = 15.34 \text{ horse power.}$$

Or, multiply the one-twelfth of the water expended per second by the fall, and the product will be the horse power—

1-12th of 20 = $1\frac{2}{3}$
9 the fall
Horse power 15 as above.

To find the discharge for a given horse-power.

From the equation $D = \frac{Hh}{mf}$ **we have the following rule:—**

Multiply the given horse power by* 44,000, *and divide the product by* 62½ *times the given fall, and the quotient will be the discharge per minute.

Example VIII.—The effective fall is 9 feet, What number of cubic feet must be discharged per second to ensure a power equal to 15.34 horses?

62.5 44000
9 15.34

562.5) 675000

The discharge 1200 cubic feet.

It happens that in the practical execution of works frequent use is made of ropes and chains; the following proportions and strength of each may prove acceptable, as also the accompanying Table for changing cubic feet into Tons weight.

TABLE FOR FINDING STRENGTH OF ROPE AND CHAIN.				TABLE FOR CHANGING CUBIC FEET INTO TONS.			
Circumference of Rope in Inches.	**Diameter of a Chain.**	**Proved to carry Tons.**	**Wt. of 1 ft. of chain lbs. avoir.**	**Feet.**	**Tons.**	**Feet.**	**Tons.**
3	5-16th	1	1·08	1	·027	300	8·35
4	6-16	2	1.5	2	·055	400	11·14
4¾	7-16	3	2·0	3	·083	500	13·93
5¼	8-16	4	2·7	4	·111	600	16·71
6	9-16	5	3·3	5	·139	700	19·50
6½	10-16	6	4·0	6	·167	800	22·28
7	11-16	8	4·6	7	·195	900	25·07
7½	12-16	9¾	5·5	8	·222	1000	27·86
8	13-16	11¼	6·1	9	·250	2000	55·72
9	14-16	13	7·2	10	·278	3000	83·58
9½	15-16	15	8·4	100	2·78	4000	111·44
10½	1 inch.	18	9·4	200	5·57	5000	139·30

By paying due attention to these rules, and the use of the Tables, every case connected with mill-power, or any other department of Hydraulic Engineering, can very readily be solved.

SECTION XVII.

OF THOROUGH-DRAINAGE.

THE AUTHOR of Nature was alone able to form the huge ridges of the Mountains, to model the Hillocks and the Valleys, to mark out the courses of the great Rivers, and give the first trace to every Rivulet; but has left to MAN the task of Draining his own habitation and the fields which are to *support* him, because this is a task not beyond his power or desire, for his chief enjoyment seems to be to struggle with the *Elements*. If he do not find things to his convenience, he must model them as fancy or necessities require, bearing constantly in mind that his exertions must be *in conformity* with the general train of operations of mechanical Nature, otherwise he would be punished sooner or later for any infraction of her rules, by a total failure and discomfiture of his exertions in producing the intended results; for Nature, ever constant in her operations, would ultimately resume her wonted position again. Hence the truth of the observation, that "KNOWLEDGE IS POWER."

The most experienced *practical* and *chemical* Agriculturists concur in assuring us of the indispensable necessity of two great operations for the successful and permanent improvement of Land—the one, *Thorough-drainage*, or the removing of the superabundant moisture to which this country is too unhappily subject; and the other, *Subsoiling*, which is the commingling the several minute parts of the surface and subsoil so as to render the admixture suitable to the growth and vegetation of plants.

The Soil, though apparently exhibiting little or no variation in quality, is, in reality, known to Agricultural Chemists, to possess such varied elements, as, by being duly modified with the addition of animal, vegetable, or other matter suited to the nature of the soil, climate, and *food* of the intended crop, would *produce a harvest indeed.*

For the primary component parts of all plants and vegetables consist of elements peculiarly suited by Nature to their existence, and which, as it were, constitute their essence, or determine them to be, *per se*, what they are. It must necessarily follow, that the soil in which these elements abound is best suited for their production. Hence the important advantages of Agricultural Chemistry, which teaches us how to select that substance for manure which is peculiarly adapted to their reproduction; and the very serious loss so frequently incurred from our ignorance or negligence of the practice thereof. For instance, should a Farmer plant seed, requiring a considerable quantity of *lime*, or any other particular substance for its reproduction, in ground possessing little or none thereof, the result is evident; it would indeed grow—sickly, and die of inanition. And *this* may be ranked among the primary *causes* of the destruction of the *potato* crops these two years past. Its component *materiel* had been wasted or exhausted; and although it attained its usual dimensions, it had not that *vis* *inertiæ*, as the Philosophers say, within it, which is well known to resist putrefaction in *living* animals.

In some soils the substance suited to the growth of plants is more abundant than in others, although originally the land may have been equally possessed thereof, but the *system* of cultivation practised by the multitude having exhausted it, and their neglect, or more truly speaking, their *inability* to supply that compensating element, manure, has caused the variety of sterility now so obvious. But beneath those parts of surface *usually* turned up in the act of tillage, and which has received the name of *subsoil*, nature, ever bountiful to man, has kindly placed a supply of those elements in which the upper surface soil is deficient, from continuous exhaustion. When this soil is turned up to a *certain* extent, those nourishing particles come within the absorbing power of the plants, which eagerly seek such nourishment; and the operation is termed SUBSOILING—the indispensable necessity for which the *Legislature* has acknowledged, and is now assisting in the great undertaking, which will, it is hoped, with the blessing of a merciful Providence, again cause plenty and happiness to flow throughout the Land.

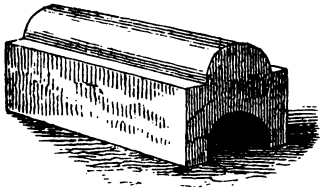
THE SYSTEM of Thorough-drainage consists in a series of *minor* covered drains, at suitable intervals, parallel to each other, discharging themselves into others of greater dimensions, called *sub-mains*, and these again into others still greater, called MAINS, until, from their size, and the quantity of water they have to discharge, they warrant us in making them open drains. Thus, figure 8 represents a field or plot of ground, and *a. b. c. d. e. f.* the *parallel* drains, which are to be cut as shown in the sections figs. 5, 6, and 7. GH may be termed an oblique *catchwater* drain, used only where the ground is too precipitous, with a view of lessening the velocity of the water downwards. KL is a sub-main larger than the others, and made for carrying off the waters to the covered Mains, which are represented by figs. 9, 10, 11.

The direction of those drains should generally be in that corresponding to the natural inclination of the land to be drained (*vide* fig. 8), and their depth should vary, according to the nature of the soil, from 33 to 42 inches, unless the expense should be too great to warrant such a depth; as in rock, gravel, &c.

Materials for drainage.—The materials used for parallel, minor, and sub-main drains, are usually broken stones or tiles, to the depth shown in the sections.

When broken stones are used, they should always be covered with what is termed in this country a *scragh*, or thin sod of lea ground, taken off and laid over the broken stones, with the grassy side down, or a few inches of clay, firmly trodden, will answer pretty well, and prevent the interposition of particles of fine earth, which would interrupt the free passage of the water, and ultimately stop its course. When *tubes* or *tiles* are used, they are generally termed *draining-tiles*, some of which are oval, others circular or semicircular, and more of them like an inverted U (see fig 7), accompanied by a *sole*, but this is not always necessary; but whether tiles or broken stones be used, examine the drain and see that it is properly cut, and that no water will stand in any part thereof, and that it has a regular uniform inclination in the bottom throughout its length.

The following is an engraving of a turf tile, as figured and described in the FARMERS' GAZETTE, 27th February, 1847, and a specimen of which can be seen at the office of the above very valuable and purely Agricultural Newspaper, 23, Bachelor's-walk, Dublin. It is certainly well adapted to the intended purpose, and, from the facility of its manufacture, should be encouraged. It is cut with an instrument in the manner of common *slane turf*, and as expeditiously.



GENERAL OBSERVATIONS.

Thorough-drainage works should never be undertaken unless clearly ascertained that the surface level of the maximum floods, in the M'AIN DRAINS, can be discharged at a level which will admit of the *sub-mains* venting their waters from the most remote points of the land proposed to be thorough-drained, at least 3 to 4 feet below the surface,* or that the highest flood in mains shall be at least 3 feet below the lowest point of the land to be thorough-drained, taking great care not to connect mains, sub-mains, or minor drains to any sluggish adjoining water-courses which may exist, but to convey them parallel (if necessary) until a suitable fall is obtained, and always connecting them in an acute angle, and at a proper level.

OPEN MAIN DRAINS.

The deepening and improving of the main drains should be commenced *first*, and gradually carried up, with an inclination of at least 4 feet per statute mile, and sunk to a depth that will admit of the free and efficient discharge of the *sub-mains*. The drain should be of a proper width at bottom,† with the side slopes at least 1 to 1, unless in rock cutting, where 6 inches in a foot will answer. Sharp angles, projecting stones, and all other impediments to the free discharge of the water, should be completely removed.

The material raised in sinking or improving the drains, where not required for top-dressing the adjoining land, filling holes or useless drains, must be removed at least 4 feet from the edge of the drain, and dressed off in a workmanlike manner.

COVERED MAIN DRAINS.

When the nature of the lands, the extent of the district, or the quantity of water to be voided, renders it necessary to form COVERED MAINS, for the reception of the water discharged from the sub-mains, their dimensions must be proportional to the amount of water to be voided, and should be well flagged at bottom, the sides built of stone or brick, and covered with a flag or arch at top; an opening of 1 foot square, with a fall of 4 feet per statute mile, will be sufficient to void the *rain* water from 60 acres of land, where there are no land springs.

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* *Vide* page 52.

† This dimension could be obtained by Table No. 2, or by the Table of pipes, and the quantity of excavation by Table 17.

SUB-MAINS.

Sub-mains should be cut 40 inches deep at least, 16 inches wide at top, and 8 to 10 inches wide at bottom. The fall in each to be as great as the main drainage of the district will allow, and should not run beyond a length of 200 yards, without discharging itself into a covered or open main drain of suitable capacity.

MINOR OR PARALLEL DRAINS.

Should be cut 33 to 42 in., or more,* deep, 12 to 16 in. wide at top, 4 in. at bottom,† and run in a straight direction parallel to each other, unless where the declivity happens to be very considerable, and then to be carried obliquely across the fall at such an angle as to insure a free discharge for the water. The fall in each minor drain should be as great as the main and sub-main drainage, previously described, will admit.

In each minor drain should be put not less than 8 nor more than 12 inches in depth, of stones, broken to a size not exceeding 2½ inches in diameter. Great care should be taken that the bottom of the drain be clean and of a uniform declivity, and that no dirt be put in with the stones; the drain should then be filled up with the stuff previously taken out, observing to keep the active soil for top-dressing.* The "putting in" of the stones should invariable be commenced at the highest point or head of the drain, and immediately after the Inspector having declared it to be in a suitable state for their reception.

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* *Vide* p. 126.

† See figures 5, 6, and 7.

FILLING IN SUB-MAINS.

Into each sub-main there should be put 10 to 12 inches of broken stones in depth, or a covered drain should be formed, if the water which is to pass through it be considerable, and the filling in completed as already described.

When tiles and soles, or pipe tiles are used in minor drains, each tile should rest equally upon two soles; that is, the junction of the two soles ought to be under the middle of the tile; or two tiles may be placed so as to form an ellipsis, the lower one being in an inverted position.

When pipe tiles are used, they are to be the diameter shown in Table 10, for Pipes suited to Thorough Drainage, according to the quantity of water which is to be carried off the land, and in each sub-main should be placed a sole and tile, or two tiles and soles side by side longitudinally.

In unfavourable ground, caused by running sand or otherwise, should the level of the conduit be likely to be disarranged, collared pipe tiles are of considerable advantage, and ought to be preferred.

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* *Vide* pp. 109, 110.

But as the object here is not to write extensively on Thorough-drainage, but to show the expense likely to be incurred therein, and also the most suitable and efficient drains for carrying off any proposed quantity of water from the lands to be drained, as it frequently happens that, for want of information, those main and sub-mains may be made either too large or too small, in the former case an unnecessary expense is incurred, and in the latter the drains are almost useless. An example will elucidate the case—

Required the dimension of a *pipe* or *tube* capable of conveying the water from any number of acres of land with any given inclination between 1 foot in 100 feet. Look for the number of acres in Table No. 1, under the head of Pipes or Tiles, and opposite will be found the discharge in cubic feet per minute. Now look for the rate of inclination at top of 10th Table, and in *that column* find the *discharge* or the next greater, and in the margin corresponding therewith will be found the diameter of the Tube required.

Example.—Let the number of acres be 5 and the *rate* of inclination 1 in 30, what should be the diameter of the *tile* or *pipe?*

Opposite to 5 acres will be found 12.5 cubic feet—which look for under the rate of inclination, and corresponding to 3.6 inches will be found 12.0 cubic feet, the required number ; therefore, a tube of that dimension will answer. If it were required to convey the waters of 10 acres through a pipe, what should be its dimensions, the fall being the same as before? Opposite to 10 acres will be found 25 cubic feet, and corresponding to the inclination given, and 4.8 inches, we have 25.1 cubic feet discharge. These calculations have been made on the principle that *one-third the rain water enters the pipes in* 12 *hours after its descent.* But should the nature of the land, &c., warrant an alteration, still the table will show the dimensions for the required quantity. When large covered or open mains are used, Table No. 2 will show the dimension that should be used.

Lest persons engaged in Drainage may happen to be misled by the apparent smallness of the pipe here found, it will be necessary to observe that when there is a great declivity or fall in the surface of the land, the greater portion of the rain water will run off on the surface, and therefore particular attention should be paid to this, for the amount of rain water that has to be discharged per minute will form the *chief difficulty* they will have to encounter; the maximum quantity has already been ascertained, but the velocity it acquires when precipitated down steep inclines, is as fluctuating as the variety of gradients, and may be observed by inspection of Table No. 10, which gives the discharge for a pipe of 12 inches diameter, with an inclination of 1 in 10; 503 cubic feet per minute, which is about 3,134 gallons: but if the inclination had been 1 in 100, the discharge would only be 127 cubic feet, or 791 gallons per minute. And if we proceed further with a less rate of inclination, say 1 in 1,000, or about 5 feet per mile, the discharge will be reduced to 10.38 cubic feet, or better than a gallon per second.—*Vide* Tables pp. 88, 89.

EXAMPLE.—Log A. for 12 in. diameter = 3.39886 Vis. 2.45
Log B. for 1 in. 1000 = 1.44876
Natural number 1.95010 = 15.67
The velocity in feet per minute 13.22
Multiplied by sectional area .7854
Gives the discharge in cubic feet per minute 10.38 or 64 gallons.—*Vide* observations on the discharge of pipes, p. 82.

The AUTHOR has invented a very simple instrument for finding the *rate of inclination* and setting off parallel drains; by it and the tables, any intelligent Man could make and lay down suitable drains for any Farm or Estate. It is represented by Figs. 18 and 19; and may be had for one guinea, with printed directions for use, on application to him, at 30, Aungier-street, Dublin.

The following Table for finding the number of cubic feet of water on any quantity of land, will be convenient to those engaged in water works. By it the dimensions required for holding any given quantity of water may be ascertained, and many other applications which our space will not allow us to insert but which the intelligent reader will readily perceive.

EXAMPLE.—It will be seen by inspection that 12 inches of water on one acre will amount to 43,560 cubic feet; and if it were 1½ inches deep it would require 8 acres to hold it, and this is the maximum quantity of water that is known to fall on the same; ⅔ of which, if divided by 1440, the number of minutes in 24 hours, will give 20. cubic feet, the amount of water which 8 acres will yield, and which must be provided for in times of floods, as may be seen by reference to Table No. 1. for pipes. And its weight may be found by Table, page 107.

Table showing the number of CUBIC FEET *of water on any number of acres of land:*

	Depth of Water in Inches.					
Acrs.	¼	½	¾	1	1½	2	12
1	907.5	1,815	2722.5	3,630	5,445	7,260	43,560
2	1851.0	3,630	5445.0	7,260	10,890	14,520	87,120
3	2722.5	5,445	8167.5	10,890	16,335	21,780	130,680
4	3630.0	7,260	10890.0	14,520	21,780	29,040	174,240
5	4537.5	9,075	13612.5	18,150	27,225	36,300	217,800
6	5445.0	10,890	16335.0	21,780	32,670	43,560	261,360
7	6352.5	12,705	19057.5	25,410	38,115	50,820	304,920
8	7260.0	14,520	21780.0	29,040	43,560	58,080	348,480
9	8167.5	16,335	24502.5	32,670	49,005	65,340	392,040
10	9075.0	18,150	27225.0	36,300	54,450	72,600	435,600

SECTION XVII.

THE USE OF THE TABLES FOR FINDING THE QUANTITIES AND COST IN THOROUGH-DRAINAGE.

Example.—To what extent will £500 drain 91 acres of land? This sum will allow £5 10s. per acre. Look in Tables Nos. 15 and 16, for this amount, according as they may be English or Irish acres, and opposite it you will find the number of lineal perches, the distance of the drains asunder, the quantity of excavation, of broken stones in cubic yards, and the number of feet of pipe-tiling required for an acre, each of which, in *this case*, will be as follows:—

Drains made as Sections Figs. 5, 6, & 7.	Irish.	British.
Distance of the drains apart, in feet .	28	16.0
No. of lineal perches of drain . .	120	165
Cubic yards of excavation (earth) .	174¼	207
„ broken stones. . .	28	28.9
Lineal feet of pipes or tiles . .	2,520	2,722
Cubic feet of excavation, in a perch of sec. 5	34.0	34.0
„ „ sec. 6	39.2	39.2
„ „ sec. 7	48.12	48.12
Cubic feet of broken stones in a perch, No. 5	4.73	4.73
„ „ No. 6	6.33	6.33
„ „ No. 7	7.86	7.86

TABLE XV.—OF THOROUGH-DRAINAGE.

SHOWING THE QUANTITIES AND EXPENSE FOR THE THOROUGH-DRAINAGE OF AN IRISH ACRE OF LAND WITH BROKEN STONES OR TILES.

Description of Land, and Section of Parallel Drain.	Distance between Parallel Drains.	Irish Lineal Perches of drains per Acre.	Cubic Yards per Acre.		Expense per Acre, with Broken Stones or Tiles.			Number of Tiles, 1 Foot each per Irish Acre.	Cost of Tiles, at 12s. per 1,000.		
			Of clay Excavation.	Of broken Stones							
	Feet.	Perches.	C. Yds.	C. Yds.	£	s.	d.	Number	£	s.	d.
Hard Subsoil,	12	280	352¼	49.0	11	13	4	5,880	3	13	6
Stiff and	13	258½	325	45.2	10	15	5	5,428	3	7	10
Sandy Clay,	14	240	302¼	42.0	10	0	0	5,040	3	3	0
Drains from 12	15	224	282	39.2	9	6	8	4,704	2	18	9½
to 20 ft. apart	16	210	264½	36.7	8	15	0	4,410	2	15	1½
	17	197½	248⅔	34.5	8	4	7	4,151	2	11	10½
See Section 5.	18	186¾	235½	32.6	7	15	7½	3,920	2	9	4
Cost 10d. per	19	177	222½	30.9	7	7	6	3,714	2	6	2
Lineal Perch.	20	168	211⅔	29.4	7	0	0	3,528	2	4	1
Freestone	21	160	232⅓	37.4	7	6	8	3,360	2	2	0
bottom,	22	152¾	221¼	35.7	7	0	0¼	3,207	2	0	1
	23	146	213	34.1	6	13	10	3,068	1	18	4
See Section 6.	24	140	203½	32.7	6	8	4	2,940	1	16	9
Drains from 20	25	134⅕	194¼	31.3	6	3	0	2,822	1	15	3
to 30 ft. apart.	26	129¼	187⅔	30.2	5	18	5½	2,714	1	13	11
	27	124½	180¾	29.1	5	14	1½	2,613	1	12	8
Cost 11d. per	28	120	174¼	28.0	5	10	0	2,520	1	11	6
Lineal Perch.	29	115⅚	168½	27.1	5	6	2	2,433	1	10	5
	30	112	162¼	26.2	5	2	8	2,352	1	9	5
Beds of Gravel	31	108⅖	193⅖	31.4	5	8	4¾	2,276	1	8	5¼
Sand and	32	105	187¼	30.4	5	5	0	2,205	1	7	6¼
Rocky	33	101⅘	181⅖	29.5	5	1	9½	2,138	1	6	9
Stratification,	34	98¾	175¾	28.6	4	18	9	2,075	1	5	11¼
from 30 to 40	35	96	171	27.8	4	16	0	2,016	1	5	2½
feet apart,	36	93¼	166⅕	27.0	4	13	3	1,960	1	4	6
	37	90⅚	161⅖	26.3	4	10	10	1,907	1	3	10
See Section 7.	38	88½	157⅖	25.6	4	8	6	1,857	1	3	2½
Cost 1s. per	39	86⅙	153¾	24.9	4	6	2	1,809	1	2	7½
Lineal Perch.	40	84	149⅖	24.3	4	4	0	1,764	1	2	0¾

TABLE XVI.—OF THOROUGH-DRAINAGE.

SHOWING THE QUANTITIES AND EXPENSE FOR THE THOROUGH-DRAINAGE OF A **STATUTE** ACRE OF LAND WITH BROKEN STONES OR TILES.

Description of Land Section of Parallel Drain and Cost.	Distance between the Parallel Drains.	Lineal Perches of Drains.		Cubic Yards per Acre.		Expense per Acre, with Broken Stones or Tiles.			Number of Tiles, 1 Foot each per Statute Acre.
		Irish Perches per acre.	Per Statute Acre.	Of Clay Excavation.	Of Broken Stones.				
	Feet.	Perches.	Perches.	Cu. Yds.	Cu. Yds.	£	s.	d.	Number
Hard Subsoil, Stiff and Sandy Clay, Drains from 12 to 20 ft. apart See Section 5. Cost 8d. per Lineal Perch.	12	173	220	277	38.5	7	6	8	3,630
	13	159½	203	255⅔	35.5	6	15	4	3,351
	14	148	188½	237	33.0	6	5	8	3,111
	15	133⅓	176	221	30.8	5	17	4	2,904
	16	129¾	165	207	28.9	5	10	0	2,722
	17	122	155⅓	195½	27.2	5	3	6½	2,562
	18	115	146⅓	184	25.9	4	17	6½	2,420
	19	109¼	139	175	24.3	4	12	8	2,293
	20	103⅔	132	166⅔	23.1	4	8	0	2,178
Freestone bottom, See Section 6. Drains from 20 to 30 ft. apart. Cost 9d. per Lineal Perch.	21	98⅔	125⅓	182½	29.3	4	14	6	2,074
	22	94⅓	120	174⅔	28.1	4	10	0	1,971
	23	90⅓	115	167	26.9	4	6	3	1,894
	24	86½	110	159⅔	25.7	4	2	6	1,815
	25	83	105½	153½	24.7	3	19	1½	1,742
	26	80	101½	147⅓	23.7	3	16	1½	1,675
	27	76¾	97¾	142	22.9	3	13	4	1,613
	28	74	94	136½	22.0	3	10	6	1,556
	29	71½	91	132⅓	21.3	3	8	3	1,502
	30	69	88	127¾	20.6	3	6	0	1,452
Beds of Gravel, Sand and Rocky Stratification, from 30 to 40 feet apart, See Section 7. Cost 10d. per Lineal Perch.	31	66¾	85	151½	24.7	3	10	10	1,405
	32	64¾	82½	147	24.0	3	8	9	1,361
	33	63	80	142⅔	23.2	3	6	8	1,320
	34	61	77⅔	138½	22.6	3	4	8½	1,280
	35	59¼	75⅓	134	21.9	3	2	9¼	1,245
	36	57¾	73⅓	130⅓	21.3	3	1	1¼	1,210
	37	55¾	71	126½	20.6	2	19	2	1,177
	38	55¼	69	123	20.0	2	17	6	1,146
	39	53	67⅓	119⅔	19.6	2	16	1¼	1,117
	40	51½	65⅔	116½	19.1	2	14	8½	1,089

And in a similar manner may be found the *expense* for making drains any distance apart, and the quantity of excavation, stones, tiles, &c., required per acre. In each case there should be from one pound to thirty shillings added to the sum found in the Tables, for the construction of main and sub-main drains.

The value of a cubic yard of broken stones may be taken as follows:—

For the Royalty per cubic yard		1d.
For quarrying per	do.	4d.
For breaking per	do.	7d.
Total amount		12d.

Value of a lineal perch of *parallel* drain:—

1-4th of a cubic yard of broken stones	3d.
1½ cubic yards of excavation	5d.
Filling-in ditto	1d.
Total amount for 1 perch, statute measure,	9d.

The following will be the estimate for draining and subsoiling a British acre, founded on this *data*—the drains being 21 feet apart, and of the description in No. 6, cross-section:—

ESTIMATE FOR A STATUTE ACRE.

126 perches *lineal* of parallel drain	£4	14	6
8 perches average per acre of sub-mains, 1s. 3d. per perch	0	10	0
5 perches of main, at 2s. 6d. per perch	0	12	6
Expense for Thorough-drainage of a Brit. acre	£5	17	0
Subsoiling and removing stones, say	2	0	0
Total expense	£7	17	0

And in the same manner an estimate for an *Irish* acre can be made.

It cannot be asserted that this sum will be the *exact truth* for every kind of land, or in every *locality*. It can only be looked upon as a *fair medium*, and a *per-centage* added or deducted according to circumstances, which the practical man can always estimate.

SPECIFICATION AND ESTIMATE FOR THE RECLAIMING OF BOGS.

If the depth of *Bog* does not exceed four or five feet and have a subsoil of clay, decomposed rock, &c., it may be cut down to that extent, and the material scattered over the adjacent surface; the draining may be, as for *arable* land, with tiles or broken stones, and consequently the expense will be nearly the same, for the facility of cutting and raising the material out of a bog will be counterbalanced by the greater extent and *depth* of cutting and the difficulty of *throwing* the excavation to a greater height. If sufficient *outlet* cannot be had, it is recommended to cut an open drain 10 to 20 feet wide, according to the *extent** of the bog, through the greatest hollow, to answer for a *reservoir*, and direct all the main and sub-mains into it.

The draining materials *made of turf* itself in such cases may be more accessible to parties about to reclaim *bog* than tiles; a specimen of which may be seen at page 112.

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* The number of hhds. in any *trench*, or reservoir, will be found by dividing the cubic contents thereof in feet by 10, and taking $\frac{1}{100}$ of the product from it. Thus, What number of hhds. will a reservoir of 100 feet long, 20 feet broad, and 6 feet deep hold?

$$\begin{array}{r}\dfrac{100\times20\times6}{10} = 1{,}200\\ \dfrac{1}{100}\quad \underline{\quad 12}\\ 1{,}188\ \text{Hhds.}\end{array}$$

ESTIMATE FOR DRAINING AN IRISH ACRE OF BOG.

Opening and putting down turf materials for 160 perches lineal, at 5d. per perch	.	£3	6	8
Proportion of main and submains .	.	0	18	4
Total per Irish acre for drainage	.	£4	5	0

GENERAL RULES FOR FINDING THE QUANTITY OF EXCAVATION OR BROKEN STONES FOR ANY DRAIN.

As many may desire to make main, sub-main, and parallel drains, of different dimensions from those given, the following rule will be useful for finding the number of cubic yards in a statute lineal perch.

Rule.—*Add the breadth of the top to that of the bottom, and multiply their sum by* HALF *the depth, and the product, divided by* 144, *will be the sectional area in square feet. Multiply this area by* 16½, *and divide by* 27, *the quotient will be the number of cubic yards in one perch lineal of the drain, the dimension being taken in inches.*

Example I.—What number of cubic yards of excavation are there in a main drain of 14 inches at bottom, 20 inches at top, and 42 inches deep?

$$\begin{array}{l} 14 \\ \underline{20} \\ 34 \times \frac{42}{2} = \frac{714}{144} = 4.958 \times 16\frac{1}{2} = 81.807 \div 27 = 3.03 \text{ cub. yds.} \end{array}$$

TO ASCERTAIN WHAT QUANTITY OF BROKEN STONES WILL FILL A PERCH OF DRAIN, SUPPOSING THEY ARE PUT IN TO ANY DEPTH.

The geometrical rule for this simple question would be more complicated than practical; we therefore substitute the following rule, which is equally true, and similar to that in the above example:—

Rule.—*Suppose the stones to be placed in the drains, find the breadth of the drain by measurement at the* SURFACE *of the stones, then add to it the bottom breadth, and multiply their sum by half the depth, and the product will be the sectional area; multiply this area by* 11, *and divide by* 18, *the quotient will be the cubic yards of broken stones, if the dimensions were taken in feet; but, if taken in inches, divide by* 144, *for the cubic contents.*

Example.—The breadth of the Bottom of a drain is 4 inches, at the surface of the broken stones 10 inches, and the depth of the stones 12 inches: Required the number of cubic yards of broken stones for one statute perch of such drain?

$$\begin{array}{l} 4 \\ \underline{10} \\ 14 \\ \underline{6} = \text{half depth} \\ 84 \times 11 = \frac{924}{18} = 51.33 \div 144 = .365 \end{array}$$

of a cubic yard.

The following General Rule will be found very expeditious, either for excavation or broken stones, in any dimension of drain:—

RULE.—*Add the top breadth to the bottom, and multiply their sum by the depth, and the product multiplied by* 21, *and then cut off* 4 *places of decimals to the right, and you have the quantity of earth work or broken stones in a statute perch—the breadths and depth being* ALWAYS *taken in inches.*

EXAMPLE.

Breadth at bottom	4	inches,
Do. at top	10	„
	14	
Depth	12	
Product	168	
Multiplied by	21	
	.3529	cub. yards.

And thus, having the cubic yards in one perch, the number of cubic yards for *any* number may be found by simple multiplication of the number of lineal perches found in Table 15 or 16, corresponding to the *distance apart.* Thus, in the last example—

The cubic contents of one perch of broken stones	.3529
Mult. by the lineal perches when 20 feet apart	132
Total quantity of broken stones for 1 stat. acre	46.58

If the drains 5, 6, or 7, be approved of, the cubic quantity of broken stones or excavation, in any number of lineal perches, may be found by multiplying the tabular number opposite the

section, in page 119, by the given number of lineal perches, and the product, divided by 27, will be the cubic contents.

Example.—How many cubic yards of excavation and of broken stones in 12 statute perches, of Section No. 6 drain?

Excavation (clay) No. 6 =	**39.2**	**Broken Stones**	**6.33**
Number of perches	**12**	**No. of Perches**	**12**
	27)470.4		**27)75.96**
Total cubic yards of excavation	**17.4**	**and of stones**	**2.81**

In the same manner may be calculated the quantity of broken stones for any other section than those selected, by taking the dimensons of the top, bottom, and depth of that portion of the drain that is to be filled with the stones.

In conclusion of this subject, we take the following observations from a pamphlet, by I. J. Mechi, of Essex:—

> "When," he says, "I first commenced draining, I had the common, but erroneous, impression that water came in at the top and sides of the drains, and that the closer they were placed the better they would draw. I therefore placed my drains 12 feet apart, cut them 32 inches deep, filled them with pipes and stones, and cut open ditches to receive the water, and thus expended unnecessarily nearly £1000. *Now*, by draining nearly five feet deep and forty feet apart, and using only one-inch pipes, I am doing the work better at one-third the cost.
>
> "If deep drainage produces more employment for the labourer, more profit for the farmer, and more food for the people, I shall be amply rewarded for all the trouble and cost of my experimental labour."

The following selection is given from Act 5 & 6 Victoria, c. 89, sect. 23, 25, 26, 149, which shows the description of

PERSONS WHO ARE QUALIFIED AS PROPRIETORS TO GIVE THEIR ASSENT IN WRITING FOR DRAINAGE MEASURES.

Persons seized of, or entitled in possession, as tenant in fee-simple, or in fee-tail, general or special;
or as tenant by courtesy.

Persons entitled under any will or settlement, deed or instrument, (except a grant, lease, or agreement in writing for such grant or lease, reserving rent,) for his own life, or that of any other persons;

or for years determinable on such lives.

Persons entitled under leases granted by a bishop, collegiate or ecclesiastical body;

or any person having immediate or derivative title, from or under same, which lease shall contain a ***toties quoties*** covenant of renewal, and also all bishops, parsons, and other ecclesiastical persons as to lands held by them in those respective characters.

Persons entitled under any grant or lease, for an estate in fee;

or for a term of years absolute, whereof forty or more years are unexpired;

or for any life or lives renewable for ever;

or for any term of years renewable for ever.

Whether such last mentioned persons shall be entitled absolutely, or as tenant in tail, or as *quasi* tenant in tail, or for his life.

Persons who are feoffees, or trustees of such land, or any such estate or interest therein aforesaid, for charitable or other purposes, or guardians of infants; husbands of feme coverts; committees of estates of idiots or lunatics; provided all such persons obtain the sanction of the Court of Chancery, before giving such undertaking.

In cases where ***several*** persons shall have, in any portion of land, such of the aforesaid estates or interests as would entitle them to be deemed proprietors, ***such*** of them shall be deemed proprietors as shall be in ***actual occupation*** of the land, or shall have such estate or interest ***next in reversion or remainder*** to the estate or interest of the person in actual occupation.

Persons having any of the following interests are qualified as ***occupying*** tenants to give validity to the assent of the proprietor, by giving their consent in writing:—

Persons in actual occupation under any grant, lease, or agreement in writing for a lease, for a life or lives, or for a term of years whereof more than fourteen shall be unexpired.

SECTION XIX.

OF EXCAVATIONS AND EMBANKMENTS.

The following *Tables* of EXCAVATIONS and EMBANKMENTS for facilitating and expediting the calculations of the cubic quantities of *Earthwork* in RAILROADS, CANALS, RIVERS, TURNPIKE ROADS, &c., being the author's *own* invention, are now *reprinted*, in connection with his HYDRAULIC TABLES, as a useful auxiliary.— *Vide* Preface.

PRACTICAL ENGINEERS, RAILROAD CONTRACTORS, &c., are well aware of the great labour, loss of time, and inconvenience attending such vast calculations, from the great multiplicity of figures requisite, when the operations are performed in the ordinary way, and the great probability of errors in such a multitudinous number of calculations, especially when the time, which generally happens, is limited, and the extent of Section running, sometimes, from ten to one hundred and fifty miles in length, presenting a very unequal and irregular surface.

Definitions.—EMBANKMENTS are artificial banks or mounds of earth used for elevating low portions of a line of railway, canal, &c., to a certain height. In their construction they should be carried up with much care and attention, and filled gradually in from the exterior towards the centre to prevent slipping.

EXCAVATION is the cutting through the earth's surface to reduce it to a certain height. It is generally performed by running a gullet through the centre, and the soil is then thrown into the waggons below. In a line of Railway or Canal the cuttings should always approximate, in cubic contents, to the quantity required for Embankments.

The most rapid method of executing the earthwork of Railways, when the excavation exceeds the embankment, is to throw part of the excavation from the side slope *to spoil* (that is to lay it on the adjacent ground), should such present itself, and which is then termed side-ling ground.

A COMMON, OR TURNPIKE, ROAD is one of the oldest artificial modes of communication, by effecting a connexion, or intercourse, between Cities, Towns, and Rural Districts.

A CANAL is an artificial groove of sufficient width, cut in the earth in a horizontal direction, and supplied by water from the adjacent rivers, springs, &c., which constitutes another mode of internal communication, chiefly confined to heavy or cumbersome articles.

A RAILROAD, OR RAILWAY, is also an artificial, but highly improved description of road-way of modern invention, effected by a Steam Engine on parallel iron plates or rails, and is, or bids fair to be the most general and expeditious mode of conveyance or communication, if we except the electric telegraph, which only communicates or transmits News.

The progress of this communication is more marvellous and extensive than any one could imagine. We are informed that " Boston, Buffalo, New York, Baltimore, Philadelphia, Washington, and other cities of the western world are enabled by it to talk *simultaneously* to each other, and are all, comparatively, neighbours. Intelligence flies through the country every minute in *flashes of Electricity*, and the merchant negotiates a loan, or consummates a purchase with the greatest ease and dispatch, although his customer is one hundred miles off, and Journals a day's journey from Congress have its proceedings in print while the speaker is in possession of " the floor."

A Plane is a uniform, even surface, and its position may be horizontal, vertical, or inclined.

A Horizontal Plane is that which is perfectly level, or which has every point in its surface equidistant from the centre of the earth, and, could such be always easily procured, would be the best form of road.

A Vertical Plane is that which is perpendicular to a horizontal one, and would be the very worst form for a road, it being impossible.

An Inclined Plane is any that is not truly horizontal or vertical, being of a higher level at one extremity than the other, and is the general form of all our common roads, and, in most instances, of railroads also, where it is sometimes termed a *gradient*, but generally applied to steep inclines or slopes.

A Section is the representation of a body cut into two parts, and may be longitudinal, vertical, horizontal, or inclined.

A Vertical Section in a longitudinal or horizontal direction, when truly made, exhibits the undulating surface of the earth, its various levels and irregularities; and a cross section shows the like inequalities in a perpendicular or oblique direction to the longitudinal section.

A RATIO is the multiple or part that one number or magnitude is of another. It exists between two numbers only, and is found by dividing the *antecedent* by the *consequent*, thus—the ratio between 12 and 6 is $12 \div 6 = 2$, and the ratio 6 to 12 is $6 \div 12 = \frac{1}{2}$.

THE RATIO OF THE SLOPES is the proportion that the Base of a slope bears to the height or depth of cutting: thus when the side slopes are 1 to 1 the cutting makes an angle of 45° with the horizon.

As this is a term which not unfrequently confuses beginners the following elucidation may place it in a clearer light, inasmuch as it relates to *Cuttings* and *Embankments.*

Let $m\,n$, Fig. 17th, be parallel to Ah, and any distance CB from it. Make BA, Bf, fh, each equal to BC, and Bd equal to its half, and from B, d, f, h, erect perpendiculars meeting $m\,n$ in C,e,g,k, and join A and the several points C,e,g,k, then will AC be the slope of 1 to 1, Ae $1\frac{1}{2}$ to 1, Ag 2 to 1, and Ah 3 to 1; the diagram explains the matter so clearly that there is no necessity for further demonstration.

PLANOGRAPHY is another description of section lately introduced by that erudite and practical Engineer, SIR JOHN MACNEIL, and sanctioned by the House of Commons, who made it a standing order, which required that a vertical section of the work should be laid down on the line of direction marked on the plan, and having the Cuttings and Embankments plotted on opposide sides, which enables the owners of property to ascertain how their land is crossed, and also its quantity and value.

THE TOP OPENING of any Excavation or Embankment is the breadth of land occupied between the outer extremities of either, and is dependant on the height of Embankment, or Depth of Cutting, Base, and the ratio of slopes.

RETAINING WALLS AND VIADUCTS are frequently used to limit the Cuttings or Embankments where Land is valuable, or some other objection or difficulty intervenes, as at the Terminus of the Dublin and Kingstown, and Drogheda Railways.

INVESTIGATION OF THE MODE OF CONSTRUCTING THE TABLES.

The investigation of the principles used in the construction of these Tables of excavations and embankments is deduced thus, see *Figs.* 3rd and 4th.

Let H and h represent the greater and less co-ordinates, or any two adjacent heights of Cuttings or Embankments, and B the Base or breadth of Roadway, r the *ratio* of the slopes corresponding to the angle of repose, and L the length of the section between the co-ordinates.

Then will $2rH + B =$ top opening at H (P)

$2rh + B =$ do. at h (Q)

$2\,r.\frac{H+h}{2} + B =$ do. for middle at $\frac{H+h}{2}$ (R)

and $(r\,H + B)\,H =$ area of greater end section at H (S)

$(r\,h + B)\,h =$ do. of lesser end section at h (T)

and $\left(r\frac{H+h}{2} + B\right)\frac{H+h}{2}$ or $\frac{r}{4}(H+h)^2 \times \frac{H+h}{2}.\,B =$ the Middle area. (N)

Now $4\,N = r\,(H+h)^2 + 2\,B\,(H+h)$ which expanded gives $4\,N = r\,H^2 + rh^2 + 2\,rHh + 2\,BH + 2\,Bh$ = 4-times M. area.

$$S = rH^2 + BH = \text{area of greater end section.}$$

$$T = rh^2 + Bh = \text{area of lesser end section.}$$

$$\because 4\,N + S + T = \overline{2r\,(H^2+h^2+Hh) + 3\,B\,(H+h)}\,\frac{L}{6}$$

$$= \overline{r\left(\frac{H^2+h^2+Hh}{3}\right) + B\left(\frac{H+h}{2}\right)}\,L =$$

Solidity of the section.—*Vide Simpson's Fluxions*, Vol. 1, pp. 178-9-10, Example 10th, usually called the *Prismoidal Formula.*

From which *formula* these Tables were thus calculated. Take half the sum of any two co-ordinates multiplied by any assumed Base, and divided by 27, will give the *Tabular* number corresponding to the sum of these ordinates and base in the Table No. 17.

Thus to find the Tabular number, in Table No. 17, for ordinates 30 and 20 with a base of 40, multiply half the sum 25 by 40 and divide the product by 27, the number of cubic feet in one cubic yard, and the quotient is 37.03, the Tabular number required.

To find the Tabular number for Table No. 18, for any two ordinates, add together the sum of their squares and rectangle, and $\frac{1}{3}$ that sum, divided by 27, the cubic feet in a cubic yard, will give the Tabular number corresponding to these ordinates. Thus to find the tabular number for the ordinates 20 and 10.

$$H^2 = 20^2 = 400$$
$$h^2 = 10^2 = 100$$
$$Hh = 20 \times 10 = 200$$

$$\frac{H^2+h^2+Hh}{3} = \frac{\overline{700}}{3} = \frac{233.343}{27} = 8.64 \text{ the Tabular}$$

number for the ordinates.

The work may be expedited by writing $h'+1 = h$. Then will $H^2 + h^2 + Hh = H^2 + h^2 + Hh' + H + 2h + 1$, and by rejecting the similar terms we have $H + 2h + 1$ = the excess of the sum of the rectangles and sum of the squares of the next greater ordinate above the former. Thus, should the Tabular number for 20 and 11 be required

To 700 the sum for ord. 20 and 10
$H = 20$
$10 \times 2 = 2h = 20$
$+1 = 1$

3)741 = 247 ÷ 27 = 9.15 = the tabular number for 20 and 11. See Table 18th opposite the co-ordinates.

Now to find for 20 and 12 to 741 as above add 43 = 784 ÷ 3 = 261.333 ÷ 27 = 9.68 Tabular Number, and so of others.

This number 43 is found by adding as above,
$20 = H$
$2 \times 11 = 22 = 2h$
$1 = 43$

The following practical Rules deduced from Equations P, Q, R, S, T, N, will prove useful.

TO FIND THE TOP OPENING FOR ANY GIVEN BASE HEIGHT AND SLOPE.

Rule.—*Add the base to twice the product of the ratio into the height, and the sum will be the top opening, thus—*

Let 20 and 10 be the greater and less co-ordinates, 3 to 1 the ratio of the slopes, 40 base, and 60 length of the section.

$20 = H$	$10 = h$
$3 = r$	$3 = r$
60	30
2	2
40 + 120 = 160	40 + 60 = 100 the top openings.

TO FIND THE AREA OF EITHER END OR MIDDLE SECTION.

Rule.—*To the product of the ratio and height add the base, and their sum multiplied by the height gives the superficies of either end or middle section.*

Thus let 20 = height greater end and 10 = height less end.

20	10	20
3 the ratio	3 the ratio	10
60	30	2)30
40 the base	40 the base	
		15 Mid. height
100	70	3 the ratio
20 the height	10 the height	
		45
2,000 the area of gtr. end	70 area of less end	40 the base

Area of Middle section = 85 × 25 = 1257

TO FIND THE SOLIDITY OF THE AFORESAID OR ANY SIMILAR SECTION OF CUTTING OR EMBANKMENT.

RULE.—*To the areas of the two ends add 4-times the middle area, and the sum multiplied by one-sixth, the length, gives the solidity.*

Thus— 2000 area of greater end, as before
700 ... less end do.
5100 4-times middle area do.

78000
10 $\frac{1}{6}$ of length

27)78000 = 2888.88 Cubic yards, the Solidity.

By the Tables

20 + 10 = 30 with base 40. Tab. Num. in Table 17 = 22.22.
Tabular No. in Table 18, corresponding to 20 and 10 = 25.92.
8.64 × 3 (the ratio) = 25.92.

48.14
length 60

Cubic yards 2888.40

Differing from the former only in the Decimal.

SECTION XX.

METHOD OF USING THE TABLES.

1st. To find the Tabular number in Table* 17, look for the sum of the co-ordinates, or heights, or depths, in the right or left-hand column, and for the given Base at the top, and in the angle of intersection, will be found the Tabular number required :—Thus, for ordinates 30 and 10, or their sum, 40 and Base 50 will be found 37.02, and for 20 and 30, and Base 36, will be found 33.33 and so of others, co-ordinates.

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* As the *entire* of each Table would not fit on one or two pages so as to exhibit it as originally constructed, these parts, of *each Table,* which are *likely* to be simultaneously used, are placed in opposite pages, so that by one opening of the book the required numbers for each may be seen.

To find the Tabular number in Table, No. 18, look for one of the co-ordinates in the margin, and for the other at the top or bottom of page, and in the angle of meeting will be found the tabular number required, thus—

The Tabular number for 24, and 0 = 7.11
for 30, and 12 = 17.33
for 40, and 20 = 34.57

And should the Tabular number for the co-ordinates 24 and 3 = 27 be required for a base of 29, multiply .250, the tabular number for 27, and base ½ by 58(=29 × 2) and it gives 14.5 the tab. num. required,* or the same may sometimes be more readily found by adding the tabular number for 28 to that of 30, and taking half the sum, which will give it thus—The Tabular number for Ordin. 27, Base, 28=14.00
27 and 30=15.00
2)29.00
14.50

as before, and in like manner *half* the tabular number for bases 40 and 50 would be 22.5, the same co-ordinate, 27, being *used;* half the tabular number for 12 gives tabular number for 6 ; half of 18 gives 9 ; half of 28 gives 14, and so of others.

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* The Bases given in Table No. 17, are those most frequently used. But should the Tabular number for any other Base be required, multiply the number under BASE ½ (which, for greater accuracy, has four places of Decimals retained), and corresponding to the sum of the ordinates, by double the given Base, and the product will be the tabular number required.

TO FIND THE SOLIDITY OF ANY CUTTING OR EMBANKMENT.

Rule.—*Multiply the Tabular number, found in Table* 18, *by the ratio of the slopes, add the product to the Tabular number found for the sum of the same ordinates in Table* 17, *and their sum multiplied by the length of the section in feet will give the solidity in cubic yards.*

Example.—Let A, Fig. 3, represent a Longitudinal section of a Railway cutting, &c., and B. cross sections thereof, with a Base of 30 ft., and slopes 2 to 1, required the quantity of Cutting and Embankment therein. Arrange the several ordinates as in the following table.

1	2	3	4	5	6	7	8
No.	Depths or Ordinates.	Tabular Number.	Length in Feet.	Solidity of Excavation.	Embankment.	Mean Breadth	Superficies in Acres.
1	0 & 24	27.55	× 1320	= 36366.00	...	78	2.340
2	24 & 9	39.89	× 643	= 25649.27	...	96	1.402
3	9 & 26	43.90	× 835	= 36656.50	...	100	1.897
4	26 & 20	64.96	× 1294	= 84058.24	...	122	3.588
Total Cubic yards, 182730.01.						$\frac{1}{100}$	9.227
							.093
						Acres	9.320

Now the Tabular Number in Table 17 corresponding to 24, the sum of the ordinates, and Base 30; is 13.33 and the Tabular Number corresponding to the said ordinates (0 and 24), as found in Table No. 18, is 7.11, which multiplied by 2 (the ratio of the slope), will be 14.22, and added to 13.33, above found, gives 27.55, which place in column 3, headed Tabular Number, this sum multiplied by 1320, the length of the section in feet, gives 36.366 the cubic yards in that part of the section which lies between the ordinates 0 and 24, which you are to enter in Column 5, headed Solidity of Excavation. Next look for 33, the sum 24 and 9 in the margin of Table No. 17, and at the top for base 30, and corresponding to them, will be found 18.33, and in Table No. 18, opposite the said ordinates, will be found 10.78, which multiplied by 2, the ratio as before, gives 21.56, which added to 18.33 =39.89, which insert under its proper head in column 3, and multiply it by 634 the corresponding length of the section, gives 25649.27 the solidity in cubic yards, which enter in column 5, and thus proceed until you come to the embankments, and enter their cubic contents in column 6, headed Solidity of Embankments; and, lastly, add the 5th and 6th columns separately, and these sums will give the quantities of Excavations and Embankments in the section.

Observations—It may happen that the numbers representing the co-ordinates may be too high for the 18th Table—in such a case multiply the Tabular Number corresponding to half the dimensions by 4, or, for a third of the dimensions, by 9, and the product, in either case, will be the true Tabular Number required. When the sides are perpendicular to the Base, or when there is no slope, the cubic quantity is found by multiplying the Tabular Number, in Table No. 17, by the length.

Thus, if it were required to find the quantity of Excavation in No. 1 section, supposing it to run through solid rock which will stand perpendicular, look for 24, the sum of the ordinates, and 30 Base in Table No. 17, and opposite will be found 13.33, which, multiplied by 1320, the length of the section in feet, gives 17595.60 the Cubic yards required.

When the sum of the Ordinates makes an odd half foot, add the corresponding number under Base ½ to the Tabular Number found for the integral part, and their sum will be the Tabular Number. Thus, the

Tabular Number for Ordinates 23, and 4½ and Base 30 will be 15 + .25 = 15.25.

The Tabular Number for half feet is found in Table 18th by dividing the Tabular Number found in the Table, corresponding to *double* the Co-ordinates, by 4. Thus—what will be the Tabular Number for 3 ft. 6 in., and 6 ft 6 in.? Look in the table for 7 by 13 (double these Ordinates), and it gives 3.81, and ¼ thereof .95 the Tabular number required.

TO FIND THE QUANTITY OF GROUND WHICH ANY CUTTING OR EMBANKMENT WILL OCCUPY IN A RAILWAY, CANAL, ETC.

Rule.—*Multiply the sum of any two co-ordinates by the ratio of the slopes, and add the given Base to the product; insert their sum in column* 7, *headed Mean Breadth, and their sum, multiplied by* 1½ *times the length in chains, and divided by* 1000, *will give a certain quantity, which insert in* 8*th column, headed Superficies, and lastly,* $\frac{1}{100}$ *part of the* 8*th column added to itself will be the entire quantity in Acres of land occupied.—See the work in the table, page* 137.

The following will find the quantity of Land occupied independently of the Tables.

Rule.—*Take half the sum of the ordinates, or extreme depths of the cutting, and find the top opening, as shown in page* 139 *Multiply this top opening by the length of the section, in feet, and the product will be the Superficial contents, in square feet, which reduce to acres in the usual way.*

Example—Required the quantity of land occupied by a Railway Cutting 1320 feet long, 12 feet high at one end and 10 feet at the other, Slopes 2 to 1, and Base 33.

$\frac{12 + 10}{2}$ = 11 mean depth

4 = double the Ratio

44

33 Base

A. R. P.

$\frac{77 \times 1320}{43560}$ = 2 1 13 the quantity of land occupied.

TABLE XVII.—OF BASES AND SUM OF ORDINATES.

Feet.	½	50	40	36	30	28	25	21	Feet.
1	.0092	.93	.74	.67	.56	.52	.46	.39	1
2	.0185	1.85	1.48	1.33	1.11	1.04	.93	.78	2
3	.0277	2.78	2.22	2.00	1.67	1.56	1.39	1.17	3
4	.0370	3.70	2.96	2.67	2 22	2.07	1.85	1.56	4
5	.0462	4.63	3.70	3.33	2.78	2.59	2.31	1.94	5
6	.0555	5.55	4.44	4.00	3.33	3.11	2.77	2.33	6
7	.0647	6.48	5.18	4.67	3.89	3.63	3.24	2.72	7
8	.0740	7.41	5.92	5.33	4.44	4.15	3.70	3.11	8
9	.0833	8.33	6.66	6.00	5.00	4.67	4.16	3.50	9
10	.0925	9.25	7.40	6.67	5.56	5.19	4.63	3.89	10
11	.1018	10.18	8.14	7.33	6.11	5.70	5.09	4.28	11
12	.1111	11.11	8.88	8.00	6.67	6.22	5.55	4.67	12
13	.1203	12.04	9.63	8.67	7.22	6.74	6.02	5 06	13
14	.1295	12.95	10.37	9.33	7.78	7.26	6.48	5.44	14
15	.1388	13.88	11.10	10.00	8.33	7.78	6.94	5.83	15
16	.1481	14.80	11.85	10.67	8.89	8.30	7.40	6.22	16
17	.1573	15.73	12.59	11.33	9.44	8.81	7.86	6.61	17
18	.1666	16.67	13.33	12.00	10.00	9.33	8.34	7.00	18
19	.1759	17.59	14.07	12.67	10.56	9.85	8 80	7.39	19
20	.1852	18.52	14.82	13.33	11.11	10.37	9 26	7.78	20
21	.1944	19.45	15.56	14.00	11.67	10.89	9.72	8.17	21
22	.2036	20.37	16.29	14.67	12.22	11.41	10.18	8.56	22
23	.2130	21.30	17.02	15.33	12.78	11.93	10.65	8.94	23
24	.2222	22.22	17.78	16.00	13.33	12.44	11.11	9.33	24
25	.2315	23.15	18.52	16.67	13.89	12.96	11.57	9.72	25
26	.2407	24.07	19.26	17.33	14.44	13.48	12.04	10,11	26
27	.2500	25.00	20.00	18.00	15.00	14.00	12.50	10.50	27
28	.2591	25.92	20.74	18.67	15.56	14.72	12.95	10.89	28
29	.2684	26.85	21.47	19.33	16.11	15.04	13.42	11.28	29
30	.2776	27.77	22.22	20.00	16.67	15.56	13.89	11.67	30
31	.2870	28.70	22.95	20.67	17.22	16.07	14.34	12.06	31
32	.2962	29.62	23.70	21.33	17.78	16.59	14.81	12 44	32
33	.3055	30.55	24.44	22.00	18.33	17.11	15.27	12,83	33
34	.3147	31.47	25.18	22.67	18.89	17.63	15.74	13.22	34
35	.3240	32.40	25.92	23.33	19.44	18.15	16.20	13.61	35
36	.3333	33.32	26.67	24.00	20.00	18.67	16.66	14.00	36
37	.3426	34.25	27.41	24.67	20.56	19.18	17.13	14.39	37
38	.3518	35.18	28.14	25.33	21.11	19.70	17.59	14.78	38
39	.3611	36.10	28.88	26.00	21.67	20.22	18.05	15.17	39
40	.3703	37.02	29.62	26.67	22.22	20.74	18.51	15 56	40
41	.3795	37.95	30.36	27.33	22.78	21.26	18.91	15.94	41
42	.3888	38.87	31.11	28.00	23.33	21.78	19.44	16.33	42
43	.3986	39.86	31.84	28.67	23.89	22.30	19.90	16.72	43
44	.4071	40.72	32.60	29.33	24.44	22.81	20.36	17.11	44
45	.4165	41.65	33.31	30.00	25.00	23.33	20.82	17.50	45
46	.4256	42.57	34.07	30.67	25.56	23.85	21.29	17.89	46
47	.4350	43.50	34.79	31.33	26.11	24.37	21.75	18.28	47
48	.4444	44.44	35.55	32.00	26.67	24.89	22.21	18.67	48
49	.4536	45.35	36.29	32.67	27.22	25.41	22.67	19.06	49
50	.4629	46.29	37.03	33.33	27.78	25.93	23.14	19.44	50
Feet.	½	50	40	36	30	28	25	21	Feet.

Table XVIII.—Of Co-Ordinates.

From 26 to 33, and 0 to 8.

Ordinates.	26	27	28	29	30	31	32	33	Feet.
	25.03	26.01	27.01	28.04	29.09	30.16	31.26	32.38	26
		27.00	28.01	29.05	30.11	31.20	32.31	33.45	27
			29.04	30.09	31.16	32.26	33.38	34.53	28
				31.15	32.24	33.35	34.48	35.64	29
					33.33	34.46	35.61	36.78	30
						35.59	36.75	37.94	31
							37.93	39.12	32
								40.33	33
Ordinates	26	27	28	29	30	31	32	33	Feet.

Feet.	0	1	2	3	4	5	6	7	8	Feet.
1	.01	.037								
2	.05	.087	.148							
3	.11	.161	.235	.333						
4	.20	0.26	0.35	0.46	0.59					
5	.31	0.38	0.48	0.61	0.75	0.93				
6	.44	0.53	0.64	0.78	0.94	1.12	1.33			
7	.61	0.70	0.83	0.98	1.15	1.35	1.57	1.82		
8	.79	0.90	1.04	1.20	1 38	1.59	1.83	2.09	2.37	7
9	1.00	1.12	1.27	1.45	1.64	1.87	2.11	2.38	2.68	8
10	1.23	1.37	1.53	1.72	1.93	2.16	2.42	2.70	3.01	9
11	1.49	1.64	1.82	2.01	2.24	2.48	2.75	3.05	3.37	10
12	1.78	1.94	2.12	2.33	2.57	2.83	3.11	3.42	3.75	12
13	2.07	2.26	2.46	2.68	2.93	3.20	3.50	3.81	4.16	13
14	2.42	2.60	2.81	3.05	3.31	3.59	3.90	4.23	4.59	14
15	2.78	2.97	3.20	3.44	3.72	4.01	4.33	4.68	5.05	15
16	3.16	3.37	3.60	3.86	4.15	4.46	4.79	5.15	5.53	16
17	3.57	3.79	4.04	4.31	4.60	4.93	5.27	5.64	6.04	17
18	4.00	4.23	4.49	4.78	5.09	5.42	5.77	6.16	6.57	18
19	4.46	4.70	4.98	5.27	5 59	5.94	6.31	6.70	7.12	19
20	4.94	5.20	5.48	5.79	6.12	6.48	6.86	7.27	7.70	20
21	5.44	5.72	6.01	6 33	6.68	7.05	7.44	7.86	8.31	21
22	5.98	6.26	6.57	6.90	7.26	7.64	8.05	8.48	8.94	22
23	6.53	6.83	7.15	7.49	7.86	8.26	8.68	9.12	9.59	23
24	7.11	7.42	7.75	8.11	8.49	8.90	9.33	9.79	10.27	24
25	7.72	8.04	8.38	8.75	9.15	9.57	10.01	10.48	10.98	25
26	8.35	8.68	9.04	9.42	9.83	10.26	10.72	11.20	11.70	26
27	9.00	9.35	9.72	10 11	10.53	10.98	11.44	11.94	12.46	27
28	9.56	10.04	10.42	10.83	11.26	11.72	12.20	12.70	13,23	28
29	10.38	10.75	11.15	11.57	12.01	12.48	12.98	13.49	14.04	29
30	11.11	11.49	11.90	12.33	12.79	13.27	13.78	14.31	14.86	30
31	11.86	12.26	12.68	13.12	13.59	14.09	14.60	15.15	15.72	31
32	12.64	13.05	13.48	13.94	14.42	14.93	15.46	16.01	16.59	32
33	13.44	13.86	14.31	14.78	15.27	15.79	16.33	16.90	17.49	33
34	14.27	14.70	15.16	15.64	16.15	16.68	17.23	17.81	18.42	34
35	15.12	15 57	16.04	16.53	17.05	17.59	18.16	18.75	19.37	35
36	16.00	16.46	16.94	17.44	17.98	18.53	19.11	19.72	20.35	36
37	16.90	17 37	17.86	18.38	18.93	19.49	20.09	20.70	21.35	37
38	17.83	18.31	18.81	19.35	19.90	20.48	21.09	21.72	22.37	38
39	18.78	19.27	19.79	20.33	20.90	21.49	22.11	22.75	23.42	39
40	19.57	20.26	20.79	21.35	21.93	22.53	23.16	23.81	24.49	40
41	20.75	21.27	21.82	22.38	22.98	23.59	24.23	24.90	25.59	41
42	21.78	22.31	22.86	23.44	24.05	24.68	25.33	26.01	26.72	42
43	22 83	23.37	23.94	24.53	25.15	25.79	26.46	27.15	27.86	43
44	23.90	24.46	25.04	25.64	26.27	26.93	27.60	28.31	29.04	44
45	25.00	25.57	26.16	26.78	27.42	28.09	28.78	29.49	30 23	45
46	26.12	26.70	27.31	27.94	28.59	29.27	29.98	30.70	31.46	46
47	27.27	27 86	28.48	29.12	29.79	30.48	31.20	31.94	32.70	47
48	28.44	29.05	29.68	30.33	31.01	31.72	32.44	33.20	33.98	48
49	29.64	30.26	30.90	31.57	32.26	32.98	33.72	34.48	35.27	49
50	30.86	31.49	32.15	32.83	33.53	34.26	35.01	35.79	36.59	50
Feet.	0	1	2	3	4	5	6	7	8	Feet.

TABLE XVII.—OF BASES AND SUM OF ORDINATES.

Continued.

Feet.	½	50	40	36	30	28	25	21	Feet.
51	.4722	47.22	37.78	34.00	28.33	26.44	23.61	19.83	51
52	.4815	48.15	38.52	34.67	28.89	26.96	24.08	20.22	52
53	.4908	49.08	39.26	35.34	29.44	27.48	24.54	20.61	53
54	.5000	50.00	40.00	36.00	30.00	28.00	25.00	21.00	54
55	.5093	50.93	40.74	36.67	30.56	28.52	25.46	21.39	55
56	.5185	51.85	41.48	37.34	31.11	29.04	25.93	21.78	56
57	.5278	52.78	42.22	38.00	31.67	29.56	26.39	22.17	57
58	.5370	53.70	42.96	38.67	32.22	30.07	26.85	22.55	58
59	.5461	54.61	43.68	39.34	32.78	30.59	27.30	22.94	59
60	.5555	55.56	44.44	40.00	33.33	31.11	27.78	23 33	60
61	.5648	56.48	45.18	40.67	33.89	31.63	28.24	23.72	61
62	.5741	57.41	45.92	41.34	34.44	32.15	28.70	24.11	62
63	.5833	58.33	46.66	42.00	35.00	32 67	29.16	24.50	63
64	.5926	59.26	47.40	42.67	35.56	33.19	29.63	24.89	64
65	.6018	60.18	48.14	43.33	36.11	33.70	30.09	25.28	65
66	.6111	61.11	48.89	44.00	36.67	34.22	30.56	25.67	66
67	.6204	62.04	49.63	44.67	37.22	34.74	31.02	26.06	67
68	.6295	62.96	50.36	45.33	37.78	35.26	31.48	26.44	68
69	.6388	63.88	51.10	46.00	38.33	35.78	31.94	26.83	69
70	.6481	64.81	51.85	46.67	38.89	36 30	32.41	27.22	70
71	.6574	65.74	52.59	47.33	39.44	36.81	32.87	27.61	71
72	.6666	66.67	53.33	48.00	40.00	37.33	33.33	28.00	72
73	.6759	67.59	54.07	48.67	40.56	37.85	33.80	28.39	73
74	.6851	68.52	54.81	49.33	41.11	38.37	34.26	28.78	74
75	.6944	69.44	55.55	50.00	41.67	38.89	34.72	29.17	75
76	.7035	70.35	56.28	50.67	42.22	39.41	35.18	29.56	76
77	.7128	71.28	57.02	51.33	42.78	39.93	35.64	29.94	77
78	.7222	72.22	57.78	52.00	43.33	40.44	36.11	30.33	78
79	.7315	73.15	58.52	52.67	43.89	40.96	36.57	30.72	79
80	.7407	74.07	59.26	53.33	44.44	41.48	37.04	31.11	80
81	.7500	75.00	60.00	54.00	45.00	42.00	37.50	31.50	81
82	.7591	75.91	60.73	54.67	45.56	42.52	37.95	31.89	82
83	.7684	76.84	61.47	55.33	46.11	43.04	38.42	32.28	83
84	.7776	77.76	62.21	56.00	46.67	43.56	38.88	32.67	84
85	.7868	78.69	62.95	56.67	47.22	44.07	39.34	33.06	85
86	.7962	79.62	63.70	57.33	47.78	44.59	39 68	33.44	86
87	.8055	80.55	64.44	58.00	48.33	45.11	40.27	33.83	87
88	.8147	81.47	65.48	58.67	48.89	45.63	40.74	34.22	88
89	.8240	82.40	65.92	59.33	49.44	46.15	41.20	34.61	89
90	.8333	83.33	66.66	60.00	50.00	46.67	41.67	35.00	90
91	.8425	84.26	67.40	60.67	50.56	47.18	42.13	35.39	91
92	.8518	85.18	68.14	61.33	51.11	47.70	42.59	35.78	92
93	.8611	86.11	68.88	62.00	51.67	48.22	43.05	36.17	93
94	.8703	87.03	69.62	62.67	52.22	48.74	43.52	36.56	94
95	.8796	87.96	70.36	63.33	52.78	49 26	43.98	36.94	95
96	.8888	88.88	71.10	64.00	53.33	49.78	44.44	37.33	96
97	.8980	89.81	71.84	64.67	53.89	50.30	44.90	37.72	97
98	.9071	90.71	72.57	65.33	54.44	50.81	45.36	38.11	98
99	.9163	91.64	73.31	66.00	55.00	51.33	45.82	38.50	99
100	.9256	92.56	74.05	66.67	55.56	51.85	46.28	38.89	100
Feet.	½	50	40	36	30	28	25	21	Feet.

TABLE XVIII.—OF CO-ORDINATES—*continued.*

FROM 34 TO 42, AND 9 TO 17.

Feet.	34	35	36	37	38	39	40	41	42	Feet.
26	33.53	34.70	35.90	37.12	38.37	39.64	40.94	42.26	43.60	26
27	34.61	35.79	37.00	38.24	39.49	40.78	42.09	43.42	44.78	27
28	35.70	36.90	38.12	39.37	40.64	41.94	43.26	44.60	45.98	28
29	36.83	38.04	39.27	40.53	41.81	43.12	44.46	45.81	47.20	29
30	37.98	39.20	40.45	41.72	43.01	44.33	45.68	47.05	48.44	30
31	39.15	40.38	41.64	42.93	44.23	45.57	46.93	48.31	49.72	31
32	40.35	41.59	42.87	44.16	45.48	46.83	48.20	49.59	51.01	32
33	41.57	42.83	44.11	45.42	46.75	48.20	49.49	50.90	52.33	33
34	42.82	44.09	45.38	46.70	48.05	49.42	50.81	52.23	53.68	34
35		45.37	46.68	48.01	49.37	50.75	52.16	53.59	55.05	35
36			48.00	49.35	50.72	52 11	53.53	54.98	56.44	36
37				50.70	52.09	53.49	54.93	56 38	57.86	37
38					53.48	54.90	56.35	57.81	59.31	38
39						56.33	57.79	59.27	60.78	39
40							59.26	60.75	62.27	40
41								62.26	63.79	41
42									65.33	42
Feet.	34	35	36	37	38	39	40	41	42	Feet.

Feet.	9	10	11	12	13	14	15	16	17	Feet.
9	3.00									
10	3.35	3.70								
11	3.72	4.09	4.48							
12	4.11	4.49	4.90	5.33						
13	4.53	4.93	5.35	5.79	6.26					
14	4.98	5.38	5.81	6.27	6.75	7.26				
15	5.44	5.86	6.31	6.78	7.27	7.79	8.33			
16	5.94	6.37	6.83	7.31	7.81	8.35	8.90	9.48		
17	6.46	6.90	7.37	7.86	8.38	8.93	9.49	10.09	10.70	17
18	7.00	7.46	7.94	8.44	8.98	9.53	10.11	10.72	11.35	18
19	7.57	8.04	8.53	9.05	9.59	10.16	10.75	11.37	12.01	19
20	8.16	8.64	9.15	9.68	10.23	10.81	11.42	12.05	12.70	20
21	8.77	9.27	9.79	10.33	10.90	11.49	12.11	12.75	13.42	21
22	9.42	9.93	10.46	11.01	11.59	12.20	12.83	13.48	14.16	22
23	10.02	10.60	11.15	11.72	12.31	12.93	13.57	14.23	14.93	23
24	10.78	11.31	11.86	12.44	13.05	13 68	14.33	15.01	15.72	24
25	11.49	12.04	12.61	13.20	13.81	14.46	15.12	15.81	16.53	25
26	12.23	12.80	13.37	13.98	14.60	15.26	15.94	16.64	17.37	26
27	13.00	13.57	14.16	14.78	15.42	16 09	16.78	17.49	18.23	27
28	13.79	14.37	14.98	15.60	16.26	16.94	17.64	18 37	19.12	28
29	14.60	15.20	15.81	16.46	17.12	17.81	18.53	19.27	20.04	29
30	15.44	16.05	16.68	17.33	18.01	18.72	19.44	20.20	20.98	30
31	16.31	16.93	17.57	18.23	18.93	19.64	20.38	21.15	21.94	31
32	17.20	17.83	18.48	19.16	19.86	20.59	21.35	22.12	22.93	32
33	18.11	18.75	19.42	20.11	20.83	21.57	22.33	23.12	23.94	33
34	19.05	19.70	20.38	21.09	21.81	22.57	23.35	24.15	24.98	34
35	20.01	20.68	21.37	22.09	22.83	23 59	24.38	25.20	26.04	35
36	21.00	21.68	22.38	23.11	23.86	24.64	25.44	26.27	27.12	36
37	22.01	22.70	23.42	24.16	24.93	25.72	26.53	27.37	28.23	37
38	23.05	23.75	24.48	25.23	26.01	26.81	27.64	28.49	29.37	38
39	24.11	24.83	25 57	26.33	27.12	27.94	28.78	29.64	30.53	39
40	25.20	25.93	26.68	27.46	28.26	29.09	29.94	30.81	31.72	40
41	26.31	27.05	27.81	28.60	29.42	30.26	31.12	32.01	32.93	41
42	27.44	28.20	28.98	29.78	30.60	31.46	32.33	33.23	34.16	42
43	28.60	29.37	30.16	30.98	31.81	32.68	33.57	34.48	35.42	43
44	29.79	30.57	31.37	32.20	33.05	33.93	34.83	35.75	36.70	44
45	31.00	31.79	32.60	33.44	34.31	35.20	36.11	37.05	38.01	45
46	32.23	33.04	33.86	34.72	35.59	36.49	37.42	38.37	39.35	46
47	33.49	34.31	35.15	36.01	36.90	37.81	38.75	39.72	40.70	47
48	34.78	35.60	36.46	37.33	38.23	39.16	40.11	41.09	42.09	48
49	36.09	36.93	37.79	38.68	39.59	40.53	41.49	42.48	43.49	49
50	37.42	38.27	39.15	40.05	40.98	41.93	42.90	43.90	44.93	50
Feet.	9	10	11	12	13	14	15	16	17	Feet.

TABLE XVII.—OF BASES AND SUM OF ORDINATES.

Continued.

Feet.	½	18	16	12	Feet.	½	18	16	12
1	.0092	.33	.30	.22	51	.4722	17.00	15.10	11.32
2	.0185	.67	.59	.44	52	.4815	17.33	15.41	11.56
3	.0277	1.00	.89	.67	53	.4908	17.67	15.70	11.78
4	.0370	1.33	1.18	.89	54	.5000	18.00	16.00	12.00
5	.0462	1.67	1.48	1.11	55	.5093	18.33	16.30	12.22
6	.0555	2.00	1.78	1.33	56	.5185	18.67	16 59	12.44
7	.0647	2.33	2.07	1.55	57	.5278	19.00	16.89	12.67
8	.0740	2.67	2.37	1.78	58	.5370	19.33	17.18	12.89
9	.0833	3.00	2.66	2.00	59	.5461	19.67	17.48	13.11
10	.0925	3.33	2.96	2.22	60	.5555	20.00	17.78	13.34
11	.1018	3.67	3.26	2.44	61	.5648	20.33	18.07	13.56
12	.1111	4.00	3.56	2.67	62	.5740	20.67	18.37	13.78
13	.1203	4.33	3.85	2.89	63	.5833	21.00	18.66	14.00
14	.1295	4.67	4.15	3.11	64	.5926	21.33	18.96	14.22
15	.1388	5.00	4.44	3.33	65	.6018	21.67	19.06	14.44
16	.1481	5.33	4.74	3.55	66	.6111	22.00	19.55	14.67
17	.1573	5.67	5.03	3.77	67	.6204	22.33	19.85	14.89
18	.1666	6.00	5.33	4.00	68	.6295	22.67	20.14	15.11
19	.1759	6.33	5.63	4.22	69	.6388	23.00	20.44	15.33
20	.1852	6.67	5.92	4.44	70	.6481	23.33	20.74	15.56
21	.1944	7.00	6.22	4.67	71	.6573	23.67	20.93	15.78
22	.2036	7.33	6.51	4.88	72	.6666	24.00	21.33	16.00
23	.2130	7.67	6.81	5.11	73	.6759	24.33	21.62	16.22
24	.2222	8.00	7.11	5.33	74	.6851	24.67	21.92	16.44
25	.2315	8.33	7.41	5.55	75	.6944	25.00	22.22	16.67
26	.2407	8.67	7.70	5.78	76	.7035	25.33	22.51	16.89
27	.2500	9.00	8.00	6.00	77	.7128	25.67	22.81	17.11
28	.2591	9.33	8.30	6.22	78	.7222	26.00	23.10	17.33
29	.2684	9.67	8.59	6.44	79	.7315	26.33	23.40	17.55
30	.2776	10.00	8.88	6.66	80	.7407	26.67	23.70	17.78
31	.2870	10.33	9.18	6.88	81	.7500	27.00	24.00	18.00
32	.2962	10.67	9.48	7.11	82	.7591	27.33	24.29	18.22
33	.3055	11.00	9.77	7.33	83	.7684	27.67	24.59	18.44
34	.3147	11.33	10.07	7.55	84	.7777	28.00	24.88	18.67
35	.3240	11.67	10.37	7.77	85	.7868	28.33	25.18	18.89
36	.3333	12.00	10.67	8.00	86	.7962	28.67	25.48	19.11
37	.3426	12.33	10.96	8.22	87	.8055	29.00	25.77	19.33
38	.3518	12.67	11.26	8.44	88	.8147	29.33	26.07	19.56
39	.3611	13.00	11.55	8.67	89	.8240	29.67	26.37	19.78
40	.3703	13.33	11.25	8.89	90	.8333	30.00	26.67	20.00
41	.3795	13 67	12.15	9.11	91	.8425	30.33	26.96	20.22
42	.3888	14.00	12.44	9.33	92	.8518	30.67	27.26	20.44
43	.3986	14.33	12.74	9.55	93	.8611	31.00	27.55	20.67
44	.4071	14.67	13.03	9.77	94	.8703	31.33	27.85	20.89
45	.4165	15.00	13.33	9.99	95	.8796	31.67	28.15	21.11
46	.4256	15.33	13.62	10.21	96	.8888	32.00	28 44	21.33
47	.4350	15.67	13.92	10.44	97	.8980	32.33	28.74	21.56
48	.4444	16.00	14.22	10 67	98	.9071	32.67	29.03	2178
49	.4536	16.33	14.52	10.89	99	.9163	33.00	29.33	22.00
50	.4629	16.67	14 81	11.11	100	.9256	33.33	29 62	22.22
Feet.	½	18	16	12	Feet.	½	18	16	12

TABLE XVIII.—OF CO-ORDINATES—*continued.*

FROM 43 TO 50, AND 18 TO 25.

Feet.	43	44	45	46	47	48	49	50	Feet.
26	44.98	46.37	47.79	49.23	50.70	52.20	53.72	55.26	26
27	46.16	47.57	49.00	50.46	51.94	53.44	54.98	56.53	27
28	47.37	48.79	50.23	51.70	53.20	54.72	56.26	57.83	28
29	48.60	50.04	51.49	52.98	54.48	56.01	57.57	59.15	29
30	49.86	51.31	52.78	54.27	55.79	57.33	58.90	60.49	30
31	51.15	52.60	54.09	55.59	57.12	58.68	60.26	61.86	31
32	52.46	53.93	55.42	56.94	58.48	60.05	51.64	63.26	32
33	53.79	55.27	56.78	58.31	59.86	61.44	63.05	64.68	33
34	55.15	56.64	58.16	59.70	61.27	62.86	64.48	66.12	34
35	56.53	58.04	59 57	61.12	62.70	64.31	65.94	67.59	35
36	57.94	59.46	61.00	62.57	64.16	65.78	67.42	69.09	36
37	59.37	60.90	62.46	64.04	65.64	67.27	68.93	70.60	37
38	60.83	62.37	63.94	65.53	67.14	68.79	70.46	72.15	38
39	62.31	63.87	65.44	67.05	68.68	70.33	72.01	73.72	39
40	63.81	65.38	66.98	68 59	70.23	71.90	73.59	75.31	40
41	65.35	66.93	68 53	70.16	71.81	73.49	75.20	76 93	41
42	66.90	68.49	70.11	71.75	73.42	75.11	76.83	78.57	42
43	68.48	70.09	71.72	73.37	75.05	76.75	78.48	80.23	43
44		71.70	73.35	75.01	76.70	78.42	80.16	81.93	44
45			75.00	76.68	78.38	80.11	81.86	83.64	45
46				78.37	80.09	81.83	83.59	85.38	46
47					81.81	83.57	85.35	87.15	47
48						85.33	87.12	88.94	48
49							88.93	90.75	49
50								92.59	50
Feet.	43	44	45	46	47	48	49	50	Feet.

Feet.	18	19	20	21	22	23	24	25	Feet.
18	12.00								18
19	12 68	13.37							19
20	13.38	14.09	14.81						20
21	14.11	14.83	15.57	16.33					21
22	14 86	15.59	16.34	17.12	17.93				22
23	15.64	16.38	17.15	17.94	18.75	19.59			23
24	16.44	17.20	17.98	18.78	19.60	20.46	21.33		24
25	17.27	18.04	18.83	19.64	20.48	21.35	22.23	23.15	25
26	18.12	18.90	19.70	20.53	21.38	22.26	23.16	24.09	26
27	19.00	19.79	20.60	21.44	22.31	23.20	24.11	25.05	27
28	19.90	20.70	21.53	22.38	23.26	24.16	25.09	26 04	28
29	20.83	21.64	22.48	23.35	24.23	25.15	26.09	27.05	29
30	21.78	22.60	23.46	24.33	25.23	26.16	27.11	28.09	30
31	22.75	23 59	24.46	25.35	26.26	27.20	28.16	29.15	31
32	23.75	24.60	25.48	26.38	27.31	28 26	29.23	30.23	32
33	24.78	25.64	26.53	27.44	28.38	29.35	30.33	31.35	33
34	25.83	26.70	27.60	28.53	29.48	30.46	31.46	32.48	34
35	26.90	27.79	28.70	29.64	30.60	31.59	32.60	33.64	35
36	28.00	28.90	29.83	30.78	31.75	32.74	33.68	34.83	36
37	29.12	30.04	30.98	31.94	32.93	33.94	34.98	36.04	37
38	30.27	31.20	32.15	33.12	34.12	35.15	36.20	37.27	38
39	31.44	32.38	33.85	34.33	35.36	36.38	37.44	38.53	39
40	32.64	33.59	34.57	35.57	36.59	37.64	38.72	39 81	40
41	33.86	34.83	35.81	36.83	37.86	38.93	40.12	41.12	41
42	35.11	36.09	37.09	38.11	39.16	40.23	41.33	42.46	42
43	36.38	37.37	38.38	39.42	40.48	41.57	42.68	43.81	43
44	37.68	38.68	39.70	40.75	41.83	42.93	44.05	45.20	44
45	39.00	40.12	41.05	42.11	43.20	44.31	45.44	46.60	45
46	40.35	41.37	42.42	43.49	44.59	45.72	46.86	48.04	46
47	41.72	42.75	43.81	44.90	46.01	47.15	48.31	49.49	47
48	43.11	44.16	45.23	46.33	47.46	48.60	49.78	50.98	48
49	44.53	45.59	46.68	47.79	48.93	50.09	51.27	52.48	49
50	45.98	47.05	48.15	49.27	50.42	51.59	52.79	54.01	50
Feet.	18	19	20	21	22	23	24	25	Feet.

SECTION XXI.

GENERAL RULES FOR FINDING THE SOLIDITY, LENGTH, BASE, AND RATIO.

The following Rules will prove frequently useful for finding any of the above quantities, when the others are given.

In the general equation $\Bigg(\frac{H^2+h^2+Hh}{3}+B\Bigg(\frac{H+h}{2}\Bigg)L=S$ when h becomes equal to H the equation will run thus— $(rh^2+Bh)\ L=S$ from which the following results arise which will be found of considerable use.

$$(1)\quad (rh+B)\,h\,L=s \qquad (2)\quad L=\frac{s}{rh+Bh}$$

$$(3)\quad h=\frac{\sqrt{\frac{4\,sr}{L}+B^2}-B}{2r} \qquad (4)\ B=\frac{s}{hL}-rh$$

$$(5)\qquad \text{and } r=\frac{s-hBL}{h^2L}$$

From the first of which we find the solidity of any excavation of a tropezoidal form, when the remaining dimensions are given; the second enables us to find the *Length;* the third the *Height;* the fourth the *Base;* and the fifth the *Ratio* of the Slopes. The following examples will serve to elucidate this subject, which is particularly useful when referred to Thorough-drainage, or when Embankments are to be made beside a River with the material taken out of its Bed.

CASE I.—Given the Base, the Ratio of the Slopes, and the Length, to find the Solidity.

RULE.—*To the Base add the product of the height and Ratio of the Slopes, and multiply the sum, the height, and length together, and the product will be the solidity.*

Example 1.—What will be the Solidity of an Embankment, or Excavation, if the Base be 10, height 12, ratio of slopes 2, and length 500 feet?

$$\begin{array}{l} 12 = h \\ \underline{\;\;2\;\;\;\;} \\ 24 + 10 = 34 \times 12 \times 500 = 204{,}000 \text{ Solidity, cubic feet.} \end{array}$$

Case II.—To find what Length of Embankment will any given quantity of Excavation make.

Rule.—*To the Base add the product of the ratio and height, and multiply their sum by the Height, and divide the product into the given Solidity, and the quotient will be the Length of the Embankment.*

Example 2.—To what extent will 204.000 Cubic feet form an Embankment on each side of a River, if the dimensions be those in Example No. 1?

$$\begin{array}{l} 12 = \text{Height} \\ \underline{\;\;2\;\;\;\; \text{Ratio}} \\ 24 + 10 = 34 \times 12 = 408)\underline{204.000} \\ \qquad\qquad\qquad\qquad\qquad\quad 2)\underline{500} \text{ entire length} \\ \text{which would make} \qquad\quad\;\; 250 \text{ on each side.} \end{array}$$

Case III.—To find what height will a certain quantity of excavation taken out of a River enable us to make an embankment of a given Base and Slope.

Rule.—*Multiply four times the Ratio by the Solidity, and divide the product by the Length, and add the square of the Base to the quotient. The square root of the sum* minus *the Base, divided by twice the ratio of the Side Slope will give the height of the embankment.*

Example 3.—What will be the Height of an Embankment, whose solidity is 204,000, Base 10, and Length 500, with Side Slopes of 2 to 1?

$$\begin{array}{l} 4 \times 2 = 8 \times \dfrac{204{,}000 = 1632000}{500} = 3264 \\ \qquad\qquad\qquad\qquad\qquad\quad \underline{100 = 10^2} \\ \text{The square root } 3364 = 58 \\ \qquad\qquad\qquad\qquad\quad \underline{10 = \text{Base}} \\ \qquad\qquad\qquad 2 \times 2 = 4)\underline{48} \\ \qquad\qquad\qquad\qquad\qquad 12 \text{ Height.} \end{array}$$

Case IV.—Given the Solidity, Slope, and Length, to find the Base.

Rule.—*Divide the Solidity by the product of the length and height, and deduct the product of the height and ratio from the quotient and the remainder will be the base required.*

Example 4.—What breadth at top will 204.000 cubic feet enable an engineer to form an embankment when the height is 12 feet, length 500, and slopes 2 to 1?

$500 \times 12 = 6000)204.000$

34

$12 \times 2 = 24$

10 the Base required.

Case V.—Required the ratio, all the rest being given.

Rule.—*From the Solidity take the continued product of the height, length, and breadth, and divide the difference by the product of the length into the square of the height, and the quotient will be the Ratio.*

The dimensions taken as in the foregoing examples we have

204.000 the Solidity

Deduct $60,000 = 500 \times 10 \times 12$

$12 \times 12 \times 500 = 72000)144000$

2 the Ratio of the slope.

As it frequently happens that calculations in this department will be required when and where there may be no Tables to assist, the following General Rule will be convenient :—

Rule.—1*st. Multiply the greater depth by the ratio of the slope, and add the product to the base, then multiply their sum by the said depth, and reserve the product. 2nd. Multiply the less depth in the same manner, and likewise reserve the product. 3rd. Multiply half the sum of the depths by the ratio and add it to the base, and multiply this sum by the mean height, and by 4, and reserve the product as before. 4th. Multiply the sum of the three reserved products by the length of the section in feet, and reserve the product. 5th. Proceed in this manner through each part of the section; and, lastly, add the reserved products, and one-sixth of their sum divided by* 27 *will be the true content, in cubic yards, of the entire, whether cuttings or embankments.*

Example.—What will be the number of cubic yards in a cutting one mile in length, base 30, ordinates or depths 27 and 9 feet, side slopes 2 to 1?

The following is the common way of performing it:—

27	$\frac{27+9}{2}=18$	9
2 ratio	2 ratio	2 ratio
54	36	18
30 base	30 base	30 base
84	66	48
27 height	× 18 mean height	9 height
588	1188	432
168	4 times	
2268	4752	

4752
2268
432
7452 sum
× 5280 the length
$\frac{1}{6}$) 39346560
27) 6557760
242,880 cubic yards.

To perform this by Tables 17 *and* 18:—

Corresponding to 36 (the sum of the depths) and 30 (the base), in Table 17,	20.0
And, corresponding to 27 and 9, in Table 18, we find 13, × 2 (the ratio) gives	26
	46 × 5280 = 242,880

We shall conclude this subject by giving another Example in the above Rule, taken from "Simms on Levelling," in which it occupies six entire pages.

Let Figure 20 represent the section of a line of old road, and let it be required to find the amount of the Cuttings and Embankments, the Depths and Lengths, as on the figure, with Base 50, side slopes for Cuttings 1½ to 1, and for Embankments 2 to 1:—

The following is an improved method (*Vide* Rule, p. 148):—

CALCULATION FOR THE CUTTINGS.

Depths. Ratio. Base. Reserved Products.

$18 \times 1\frac{1}{2} = 27 + 50 = 77 \times 18 = 1386$

$9 \times 1\frac{1}{2} = 13\frac{1}{2} + 50 = 63\frac{1}{2} \times 9 \times 4 = 2286$

Sum $3672 \times 561 = 2059992$ (*a*)

$18 \times 1\frac{1}{2} = 27 + 50 = 77 \times 18 = 1386$

$20 \times 1\frac{1}{2} = 30 + 50 = 80 \times 20 = 1600$

$19 \times 1\frac{1}{2} = 28\frac{1}{2} + 50 = 78\frac{1}{2} \times 19 \times 4 = 5966$

Sum $8952 \times 858 = 7680816$ (*b*)

$20 \times 1\frac{1}{2} = 30 + 50 = 80 \times 20 = 1600$

$10 \times 1\frac{1}{2} = 15 + 50 = 65 \times 10 \times 4 = 2600$

Sum $4200 \times 825 = 3465000$ (*c*)

Total 1-6th $)\overline{13205808}$

$3\,)\,\overline{2200968}$

$9\,)\,\overline{733656}$

True content in cubic yards 81517.33

FOR THE EMBANKMENTS.

$19 \times 2 = 38 + 50 = 88 \times 19 = 1672$

$9\frac{1}{2} \times 2 = 19 + 50 = 69 \times 9\frac{1}{2} \times 4 = 2622$

$4294 \times 820 = 3521080$ (*d*)

$19 \times 2 = 38 + 50 = 88 \times 19 = 1672$

$8 \times 2 = 16 + 50 = 66 \times 8 = 528$

$13\frac{1}{2} \times 2 = 27 + 50 = 77 \times 13\frac{1}{2} \times 4 = 4158$

$6358 \times 825 = 5245350$ (*e*)

$8 \times 2 = 16 + 50 = 66 \times 8 = 528$

$4 \times 2 = 8 + 50 = 58 \times 4 \times 4 = 928$

$1456 \times 330 = 480480$ (*f*)

$6\,)\,\overline{9246910}$

$3\,)\,\overline{1541151}$

$9\,)\,\overline{513717}$

The true content in cubic yards 57079.66

The same performed by Sir John MacNeill's Tables—

THE CUTTINGS.

COMPUTATION OF *a*.

Tabular No. . . . = 22·67
Length 561

2267
13602
11335

Cont. in cub. yards = 12717·87

COMPUTATION OF *b*.

Tabular No. . . = 55.26
Length 858

44208
27630
44208

Cont. in c. yds. = 47413.08

COMPUTATION OF *c*.

Tabular No. . . . . = 25·92
Length 828

Cont. in cub. yards = 21384.00

CUTTINGS.

a = 12717·9
b = 47413·1
c = 21384·0

Total c. yards 81515·0

THE EMBANKMENTS.

COMPUTATION OF *d*.

Tabular No. . . . = ·3519
Base 50

17·5950
Tabular No. . . = 8·914

26·509
Length 820

530180
212072

Cub. content . = 21737·380

COMPUTATION OF *e*.

Tabular No. . . = .5000
Base 50

25·0000
Tabular No. . = 14·247

39·247
Length . . . 825

196235
78494
313976

Cub. content = 32378·776

COMPUTATION OF *f*.

Tabular No. . . . = ·1481
Base 50

7·4050
Tabular No. . . . = 1.580

8·985
Length 330

Cub. content . . . 2965·050

EMBANKMENTS.

d = 21737·4
e = 32378·8
f = 2965·0

Total c. yards 57081·2

Calculated by the Tables in this work :—

FOR THE CUTTINGS.

(*a*)
In 17th Table = 16.67
18th do. × 1½ = 6.00
Sum 22.67
The length 561
Cubic yards 12717.87

(*b*)
In Table 17th = 35.18
In Tab. 18th × 1½ 20.07
Sum 55.25
The length 858
Cubic yards 47413.08

(*c*)
In 17th Table = 18.52
In 18th do. × 1½ = 7.41
Sum 25.93
The length 825
Cubic yards 21392.25

Total Excavation.
(*a*) 12717.87
(*b*) 47413.08
(*c*) 21392.25
Cubic yards 81523.20

FOR THE EMBANKMENTS.

(*d*)
In Table 17th = 17.59
In 18th do. × 2 = 8.92
Sum 26.51
The length 820
Cubic yards 21738.20

(*e*)
In 17th Table = 25.00
In 18th do. × 2 = 14.24
Sum 39.24
The length 825
Cubic yards 32373.00

(*f*)
In Table 17th = 7.41
In Table 18th × 2 = 1.58
Sum 8.99
The length 330
Cubic yards 2966.70

Total Embankments.
(*d*) 21738.20
(*e*) 32373.00
(*f*) 2966.70
Cubic yards 57077.90

Recapitulation of the total quantities by each method :—

	Cuttings.	Embankments.
By Sir J. Macneill's Tables	81515.00	57081.20
By Tables in this work	81523.20	57077.90
The true quantities	. 81517.33	57079.66

These results may be considered very exact, as an alteration in the second decimal place of an unit, when the cutting runs 800 feet long, would cause a difference of 8 cubic yards in the quantities.

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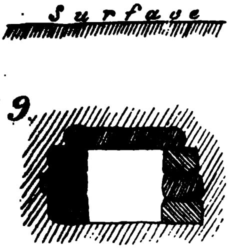
BOUNDAR
A 10
B 16
C 25
S

9.



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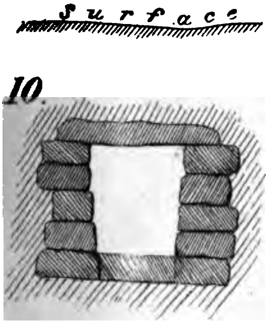

11.